PB-231 372

DAIRY FOOD PLANT WASTES AND WASTE TREATMENT PRACTICES

Ohio State University Research Foundation

March 1971

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

PB 231 372

1 **Accession Number**
W

2 **Subject Field & Group**

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 **Organization**
The Ohio State University Research Foundation, Columbus, Ohio

6 **Title**
Dairy Food Plant Wastes and Waste Treatment Practices

10 **Author(s)**
Harper, Dr. W. James
Blaisdell, Dr. J. L.
Grosshopf, Jack

16 **Project Designation**
EPA, WQO Grant No. 12060-EGU

21 **Note**

22 **Citation**

23 **Descriptors (Starred First)**
*Dairy Wasters, *Waste Treatment, Whey, Milk, Cheese, Butter, Ice Cream, BOD, COD, Suspended Solids, Microbiology, Biochemistry

25 **Identifiers (Starred First)**

27 **Abstract**
This paper reports a comprehensive study of the state-of-the-art of dairy wastes, their control and treatment, both from the point of view of past literature and current industrial knowledge and practice. Research needs are reviewed in light of on-going research and the priority of the needs.

The dairy industry has only limited knowledge of the Biological Oxygen Demand (BOD) of its waste waters. Even less information is available concerning Chemical Oxygen Demand (COD) and refractory organic and inorganic components of these wastes.

BOD-COD relationships are reviewed together with available knowledge on all aspects of waste composition. Sources and control of in-plant wastes are presented. Detergents and sanitizers contribute to the BOD load, to refractory COD and to the toxicity of some dairy food plant wastes.

Waste treatment methods are critically reviewed. The basic information needed for intelligent design of dairy food plant waste treatment facilities and for their optimal operation are not generally available. Most dairy waste treatment systems fail at least once a year and generally are less than 75% efficient about 25% of the time. Problems of shock loading, whey, cottage cheese wash water and the presence of surfactants appear to contribute to the difficulty of continuing efficient dairy food plant waste treatment.

This report was submitted in fulfillment of Grant No. 12060-EGU between the Water Quality Office of the Environmental Protection Agency and The Ohio State University Research Foundation.

Abstractor
Dr. W. James Harper

Institution
The Ohio State University Research Foundation

WR 102 (REV. JULY 1969)
WRSIC

SEND, WITH COPY OF DOCUMENT, TO: WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON, D. C. 20240

GPO: 1970 - 407 -891

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

☆ U. S. GOVERNMENT PRINTING OFFICE : 1972 720-956/358

DAIRY FOOD PLANT WASTES AND WASTE TREATMENT PRACTICES

by

Department of Dairy Technology
The Ohio State University
Columbus, Ohio 43210

for the

Office of Research and Monitoring

ENVIRONMENTAL PROTECTION AGENCY

Grant # 12060 EGU

March 1971

EPA Review Notice

This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

This paper reports a comprehensive study of the state-of-the-art of dairy wastes, their control and treatment, both from the point of view of past literature and current industrial knowledge and practice. Research needs are reviewed in light of ongoing research and the priority of the needs.

The dairy industry has only limited knowledge of the Biological Oxygen Demand (BOD) of its waste waters. Even less information is available concerning Chemical Oxygen Demand (COD) and refractory organic and inorganic components of these wastes.

BOD-COD relationships are reviewed together with available knowledge on all aspects of waste composition. Sources and control of in-plant wastes are presented. Detergents and sanitizers contribute to the BOD load, to refractory COD and to the toxicity of some dairy food plant wastes.

Waste treatment methods are critically reviewed. The basic information needed for intelligent design of dairy food plant waste treatment facilities and for their optimal operation are not generally available. Most dairy waste treatment systems fail at least once a year and generally are less than 75% efficient about 25% of the time. Problems of shock loading, whey, cottage cheese wash water and the presence of surfactants appear to contribute to the difficulty of continuing efficient dairy food plant waste treatment.

This report was submitted in fulfillment of Grant No. 12060-EGU between the Water Quality Office of the Environmental Protection Agency and The Ohio State University Research Foundation.

TABLE OF CONTENTS

Page

LIST OF FIGURES ix

LIST OF TABLES xiv

SECTION

I CONCLUSIONS 1

II RECOMMENDATIONS 5

III INTRODUCTION 9

IV SIGNIFICANT INDUSTRIAL TRENDS 11

Trends in the Nature and Structure of the Dairy Food Industry 11

V DAIRY FOOD INDUSTRY'S KNOWLEDGE TOWARDS WASTE LOADS AND WASTE TREATMENT 19

VI DAIRY PLANT WASTES 27

Biological Oxygen Demand (BOD) 30

BOD for Various Dairy Products 30
BOD_5 for Various Milk Constituents and Related Components 33
BOD_5 and Waste Water Volume Coefficients for Commercial Dairy Food Plant Wastes 36
BOD-COD Interrelationships 48
Other Characteristics of Dairy Food Plant Wastes 64

Solids 64

Chemical Composition of Dairy Food Plant Waste Waters 69
Detergents and Sanitizers 79
Contribution of Detergents and Sanitizers to Dairy Food Plant Waste Water From Industrial Plants 93

Variations in Dairy Food Plant Wastes 98

Variations during the Processing Day 99
Day-to-Day Variations in Dairy Food Plant Wastes 103

VII SOURCES OF DAIRY FOOD PLANT WASTES 125

Flow Sheets for Various Dairy Food Plant Operations 125

Preceding page blank

SECTION Page

Waste Water Volume Coefficient for Various Plant Operations 138

Sources of BOD 138

Waste from Individual Unit Operations 149
Role of Condensate in Cooling Waters 166

In-Plant Control of Dairy Plant Wastes 171

Comparison of Plant Reported Wastes with Wastes Calculated from BOD_5 Values 171

Management Quality and Waste Coefficients 173

Good Management Practices in Waste Control 174

Reduction in Wastes Through Proper Design and Utilization of Engineering Processes 181

Engineered Reduction of Losses from High Volume HTST Pasteurizing Units 182
Reduction of Loss Through Continuous Processing 186

Segregation of Wastes 190

Detergents Concentration and Volume 191
Control of Waste Water Through By-Product and Waste Product Utilization 192

VIII DAIRY FOOD PLANT WASTE WATER TREATMENT 195

Microbiology of Dairy Food Plant Waste Water Treatment 195

Mechanism of Biological Oxidation 195

Microflora 199

Activated Sludge 199
Trickling Filter 206
Oxidation Ponds 208
Anaerobic Digestion 208
Factors Affecting Microbiological Activity in Dairy Food Plant Wastes 209

TABLE OF CONTENTS (Continued)

SECTION | Page

IX WASTE TREATMENT METHODS 215

Activated Sludge Treatment 215

U.S.D.A. Research 215
Assimilation of Dairy Wastes 216
Endogeneous Respiration 218
Reviews 220
Summary 226
BOD and COD Kinetic Data 228
Differences Among Treatment Systems 234
Sludge Settling Characteristics 252
Sludge Filtration 261
Flotation 262
Loss in Sludge Activity 264
Activated Sludge Performance Data 265
Operational Problems of Activated Sludge Systems 281

Biological Filtration 289

BOD Removal Relationships 290
Experimental Values for Rate Constants 293
Sludge Yields 297
Performance Data 300
Loading Sensitivity 309
Industrial Experiences 316
Experiences with Whey 318
Plastic Media 319
Treatment Problems 321

Anaerobic Treatment 322

Literature Experiences 333
Performance Data 341
Operational Problems 341

Lagoons 344

Experiences with Dairy and Whey Wastes 363
Performance Data 368
Operational Problems 368

Irrigation 375

Other Experiences with Dairy Wastes 387
Performance Data 392
Comments on State of the Art of Irrigation 392

TABLE OF CONTENTS (Continued)

SECTION | Page

Economics of Dairy Food Plants Waste 400

Effects of Limits on Waste Composition Going Into Municipal Treatment Plants 400
Effect of Surcharge on Waste Composition 401
Cost of Waste Water Treatment Facilities 405
Cost of Waste Treatment Plant Facilities and Operation 405

Experiences of Consulting Engineers With Dairy Food Plant Waste Treatment 412

X SELECTED DAIRY PLANT CASE HISTORIES 415

Plant 1 415
Plant 2 416
Plant 3 417
Plant 4 417

XI ACKNOWLEDGEMENTS 419

XII REFERENCES 421

Addendum to References Cited 510

XIII APPENDICES 521

Survey Forms Used in Study 523

Bibliography - Annotation 531

LIST OF FIGURES

Figure No.		Page
1	Past and projected trends in the number of various types of dairy plants in the United States	12
2	Past and projected production per day for various types of dairy plants in the United States	13
3	Past and projected annual production of selected dairy foods in the United States	15
4	Comparison of BOD with O.C. (COD) of dairy wastes (after Hoover, 466)	59
5	Percentage distribution of waste water temperature for 10 commercial dairy food plants	70
6	Relation of mineral components to BOD of milk wastes	77
7	Pounds BOD_5/1000 pounds of milk processed for average surfactants and acids in dairy food detergents	90
8	Twenty-four hour recorder chart of effluent temperature on typical day before conservation practices put into effect	100
9	Twenty-four hour recorder chart of effluent temperature on typical day after conservation practices put into effect	101
10	Hourly variations in ppm BOD_5 pounds BOD_5 and waste water volume for dairy plant A	102
11	Hourly variations in ppm BOD_5, COD and waste water volume for dairy plant B	104
12	Hourly variations in waste water volume for a dairy plant on two consecutive days (687)	105
13	Distribution of waste water volume for a processing day in one dairy plant (687)	106
14	Distribution of ppm BOD and COD during a one day operation of one dairy plant (1201)	107
15	Distribution of daily BOD_5 (ppm) variation in various dairy food plant waste waters (Number refers to literature reference numbers)	108

LIST OF FIGURES (Continued)

Figure No.		Page
16	Daily variation in ppm BOD_5, fat and protein for waste water from a dairy food plant (Walgren, 1968)	109
17	Daily variation in BOD_5 and COD for waste water from a dairy food plant (McKinney and Schwin, 1960)	111
18	Variation in daily waste water discharged by Dairy Food Plant B	112
19	Variation in daily waste water volume discharged by food plant D	113
20	Daily variation in BOD_5 and COD for dairy food plant F	115
21	Daily variation in suspended solids in waste water from dairy food plant D	116
22	Daily variation in suspended solids in waste water from dairy food plant E	117
23	Daily variation in pH of waste water from dairy food plant E	118
24	Comparison of hourly, daily and monthly variability in BOD from waste water from dairy food plant B	119
25	Comparison of variability of BOD_5 values (monthly averages) in waste waters from different commercial dairy food plants	120
26	Variability in monthly averages of BOD_5 values in waste water from plant B for two different years	122
27	Variability in monthly averages of BOD_5 in waste water from dairy food plant G for four different years	123
28	Effect of viscosity on percentage of product remaining on equipment surfaces after two minutes draining	168
29	Pasteurization recycle system, initiation of water to product separation	183
30	Pasteurization recycle system, half-way through separation	184

LIST OF FIGURES (Continued)

Figure No.		Page
31	Pasteurization recycle system, nearing change in recycle valve	185
32	Effect of time after change from water to milk on fat content of waste water going to drain during pasteurization start-up	187
33	Fat losses as a function of time during start-up and shut-down of a 60,000 pound/hour HTST pasteurizer	188
34	Diagrammatic presentation of automated system for minimizing milk losses by continuous blending of products at HTST pasteurizer balance tank, eliminating need for pasteurizer shut-down during product change-overs	189
35	Floor drain system for segregation of high and low solids waste waters in a dairy food plant	190
36	CIP system to reduce cleaning compound concentration in dairy food plant waste water	191
37	Growth yield of a Sphaerotilus and an Arthrobacter species under well-aerated and nonaerated conditions	210
38	Diagrammatic representation of changes in lactose, protein, pH and dissolved oxygen during activated sludge treatment of dairy food plant waste water	212
39	Oxygen depletion in activated sludge treatment of varying concentrations of skim milk solids	219
40	Purification, oxidation, storage and synthesis for 1000 ppm sludge and 1125 ppm skim milk COD (after Porges et al. (834).	240
41	Oxygen-transfer characteristics in dilute solutions of sodium lauryl sulfate (after Echenfelder (312a, 314a))	249
42	BOD removal probability for activated-sludge treatment of dairy wastes (Plant 8)	275
43	BOD removal probability for activated-sludge treatment of dairy or dairy and municipal wastes after data from Pipes (815a)	276

LIST OF FIGURES (Continued)

Figure No.		Page
44	BOD removal probability for activated-sludge treatment of dairy and municipal wastes after data from Pipes (815a)	277
45	The influence of the sludge volume index, and the sludge recycle ratio, R/Q upon the MLSS concentration available in the aeration basin, after Stewart (1058a)	283
46	Activated sludge process flow diagrams, after Stewart (1058a)	285
47	Influence of BOD removal velocity, day^{-1} upon sludge volume index, mℓ/gram (857a)	287
48	Influence of BOD removal velocity, day^{-1} upon sludge volume index, mℓ/gram (857a)	287
49	Suggested sludge volume index, pinpoint floc formation, effluent substrate, and overall effluent BOD dependence upon loading factor, pound BOD applied per day, pound MLVS (after Stewart (1058a))	288
50	Performance chart for two-stage trickle filter on dairy wastes (after Trebler and Harding (1133))	308
51	Performance of recirculation and alternating double filtration systems (after Christensen (228))	310
52	Probability of BOD removal for the trickling filter (TF), clarifier (c) systems studies by Morgan and Bauman (729)	311
53	Performance of a trickling filter (after Wieselberger (1247))	312
54	Scatter diagram of trickling filter performance (after Table 85)	314
55	Scatter diagram of trickling filter performance (after Fig. 54 and Table 85)	315
56	Schematic diagram of relative concentrations during the course of an anaerobic fermentation (after Malina (651a) and Andrews (256))	325

LIST OF FIGURES (Continued)

Figure No.		Page
57	Effect of loading on BOD removal in contact unit (after (954))	328
58	Effect of sludge age on BOD removal in contact process (after (954))	328
59	Effect of BOD loading and sludge age on the performance of the rapid adsorption at 35°C (after 954))	328
60	Effect of temperature on BOD removal (after 952))	330
61	Effect of BOD loading on odor, turbidity, and volatile acids in treated effluent from contact unit (after 954))	332
62	Effect of separator loading on total sludge depth in treatment of milk waste (after (954))	334
63	Effect of separator loading on total sludge depth in treatment of milk waste (after (954))	334
64	Effect of separator loadings on total sludge depth (after 954))	335
65	BOD reduction as a function of detention period and influent pH (light intensity = 1,000 ft-c) after Pipes (815)	351
66	BOD reduction as a function of influent pH and detention period (light intensity = 1,600 foot-candle) after Pipes (815)	351
67	Graphical representation of proposed equations of El-Baroudi and Moawad (323)	354
68	Graphical comparison of calculated curves and experimental points of El-Baroudi and Moawad	356
69	Variation of x_f with loading rate	358
70	Cost of BOD surcharge for different standard unit operations and fluid milk with different levels of BOD as a function of milk processed	406
71	Cost of BOD surcharge for whey, cottage cheese wash water and fluid milk plants with different levels of BOD as a function of milk processed	407

LIST OF TABLES

Table No.		Page
1	Summary of Knowledge of Dairy Food Plant Loads by Dairy Food Firms	20
2	Summary of Dairy Food Plant Waste Knowledge by Plant Type	22
3	Percent Knowledge of BOD	23
4	Average Composition of Milk and Milk Products (100 g)	28
5	Whey - Cheese Conversion Factors	29
6	Literature Values for BOD of Various Dairy Products	31
7	Industrial BOD_5 Values for Selected Dairy Products	32
8	Reported BOD Value for Various Milk Constituents and Related Constituents	33
9	Percentage of Theoretical Oxygen Utilization by Pure Compounds	34
10	A Comparison of Literature and Calculated BOD_5 Values and Percentage Contribution of Milk Components to Product BOD_5	35
11	Reported Pollution Coefficients for Dairy Plant Waste in Pound BOD_5/1000 Pounds Product Produced	37
12	Reported Pollution Coefficients for Dairy Plant Waste in Pound BOD_5/1000 Pounds Product Produced	39
13	Waste Volume Coefficients for Dairy Plant Wastes	40
14	Significance of Cooling Water in Dairy Food Plant Waste Water	40
15	Calculated Waste Coefficients from Waste Profile No. 9 (355)	42
16	Waste Coefficient for Various Dairy Plants in Denmark (1236)	43
17	Dairy Plant Wastes - BOD_5, Waste Volume, and Waste Volume Coefficients	44

LIST OF TABLES (Continued)

Table No.		Page
18	Summary of Literature Values of Waste Water Coefficients	47
19	Survey of Milk Volume, Waste Water Volume, ppm BOD and Calculated Waste Water Coefficients for Industrial Dairy Food Plants of Varying Types	49
20	Summary of Commercial Plant Survey for Waste Water Coefficients	54
21	BOD$_5$/COD Ratio of Milk Products	55
22	BOD/COD Ratios of Various Milk Constituents and Related Products	56
23	BOD$_5$/COD Ratios for Raw Dairy Plant Wastes	57
24	BOC/COD Relationships in Raw and Treated Dairy Plant Wastes (1967) at Hourly Intervals	60
25	BOD$_5$:COD Relationships in Dairy Plant Raw Waste Water at Hourly Intervals During a One-Day Period	61
26	COD:BOD Ratios for the Waste from a Soap Manufacturing Plant (Eckenfelder-Industrial Water Pollution Control, 1966)	62
27	BOD$_5$/COD Relationships in Raw and Treated Dairy Plant Wastes from Survey of Industrial Dairy Plants	63
28	Literature Values for BOD - Solids Relationships and pH of Industrial Dairy Plant Wastes	65
29	BOD - Solids Relationships in Dairy Food Plant Waste Waters	67
30	BOD - Solids Relationship from Industrial Dairy Food Plant Wastes	68
31	Temperature of Dairy Food Plant Waste Water	69
32	Concentrations of Inorganic Refractory Ions Causing Damage	72
33	Effectiveness of Sewage Treatment, Natural Purification, and Water Treatment on Removal of Common Inorganic Ions	73

LIST OF TABLES (Continued)

Table No.		Page
34	Chemical Constituents of Industrial Dairy Plant Wastes	74
35	Content of Mineral Matter and Nitrogen in Milk and Its Products and By-Products	76
36	Mineral Composition of Dairy Food Plant Waste Water	78
37	Properties of Common Cleaner Components	80
38	Chemical Nature of Wetting Agents in Detergents	82
39	BOD_5 of Materials Used in the Manufacture of Detergents, Sanitizers and Lubricants	85
40	Coefficients of Components of Cleaners and Sanitizers, Pound/1000 Pound Milk Processes	89
41	Classes of Available Chlorine Compounds	92
42	Recommended Concentrations and Time of Exposure	94
43	Contribution of Detergents and Sanitizers to Dairy Food Plant Waste Waters	95
44	Dairy Variations in Waste Water Characteristics for a Commercial Food Plant (F) Manufacturing Milk and Cottage Cheese	114
45	Changes in Production and Waste Loads Over a Five Year Period for Dairy Food Plant (G)	124
46	Coefficient Water Use for Various Plant Operations	144
47	Average Reported/BOD Losses for Various Dairy Food Plant Unit Operations	145
48	Industrial Data for BOD Coefficients for Unit Processes in Two Fluid Milk, Cottage Cheese Plants	147
49	BOD Coefficients for Cottage Cheese Operations	165
50	BOD Coefficients for Whey and Wash Water from Cottage Cheese Manufacture	165
51	BOD in Condensate Waste Waters	166

LIST OF TABLES (Continued)

Table No.		Page
52	Effect of Product Composition on Residual Solids Left on Processing Equipment Surfaces	167
53	Effect on Milk Losses of Methods of Feeding Cans to Washer (1,000 10-gal cans)	169
54	Volume and Fat Content of Rinse Waters from Various Types of Dairy Food Plant Equipment	170
55	Sanitizer Utilization in the Sanitation of Dairy Food Plant Equipment	170
56	Comparison of Cleaning Compound and Cleaning Solution Usage in Recycle CIP Systems in Two Fluid Milk-Cottage Cheese Plants of the Same Size	171
57	Comparison of Reported and Calculated Milk Solids Losses	172
58	The Effect of Management Practices on Waste Coefficients	175
59	Predominant Bacteria in Skim Milk Sludges	201
60	Microbial Composition, in Percent of the Total Number of Strains Tested, of the Activated Sludge in the Endogenous and in the Assimilative Phase (a and b are duplicate flasks; samples were taken 28 (1) and 56 (2) days after the start of the experiment) (3)	202
61	Activated Sludge Microbiology and Waste Plant Characteristics	204
62	Growth Yields of Three Representative Bacteria of Dairy Waste Activated Sludge with Artificial Dairy Waste as the Substrate	209
63	The Effect of Added Substrates on Settling Properties of Activated Sludge	213
64	Pseudo First Order Rate Constant for Oxygen Consumption of "Dairy Wastes" k Days^{-1} in BOD Bottles or Shaker Flasks	229
65	Oxygen Consumption of "Dairy Wastes" k Days^{-1} in Laboratory Aerators or Activated Sludge Plants	230

LIST OF TABLES (Continued)

Table No.		Page
66	Values of K_s for Various Substrates (after 314)	231
67	Temperature Effects on Waste Treatment Processes	237
68	Conversion of Organic Materials During Biological Treatment	238
69	Sludge Endogenous Respiration	242
70	Yield and Demand Parameter for a Synthetic Waste	245
71	Influence of Waste Characteristics on Gas Transfer	248
72	Operational Parameters and Sludge Characteristics for Several Activated Sludge Plants Receiving Dairy or Dairy and Municipal Wastes, after Pipes (815a)	254
73	Sludge Classification Used by Pipes (815a)	256
74	Summary of Activated Sludge Settling and Performance Characteristic for Plants Treating Dairy or Dairy and Municipal Waste, for Data of Pipes (815a)	256
75	Operational and Sludge Values for a Milk, or Milk Whey Wastes with Ferrous Sulfate Added at a Rate of 150 g/m^3 (after Fürhoff)	259
76	Sludge Characteristics for Oxidation Ditches, after Nehrkorn and Replok (751, 873), Muskat (747a), and Wöste and Nehrkorn (1276)	260
77	Performance of Activated Sludge Treatment Systems	267
78	Performance of Oxidation Ditches Treatment Systems	272
79	Efficiency of BOD Removal by Biological Treatment of Dairy Plant Wastes - Industrial Survey Data	274
80	Activated Sludge Processes, Typical Loadings and Efficiencies (after Stewart (1058a))	284
81	Rate Constants for Trickling Filtration of Whey-Sewage Containing Wastes (after Quirk et al. (857b))	294
82	Comparison of BOD Removal Rate Constants for Trickling Filtration of "Whey" With Those of Other Wastes (after Quirk et al. (857b))	295

LIST OF TABLES (Continued)

Table No.		Page
83	Summary of Data on Nitrification in Trickling Filter (after Blakrishran and Eckenfelder (142))	296
84	Comparison of Sludge Thickening Characteristics (after Quirk et al. (857b))	298
85	Performance of Trickling Filter Treatment Systems	301
86	Loadings and Depths of Trickling Filters (after (350, 1238))	300
87	Comparison of the Performance of Granite and Plastic Media Treating Simulated Milk Waste (Rate of Application of Waste 200 gal/yd^3/day (1290 ℓ/m^3/day)(after Wheatland (1240))	320
88	Performance Data for Anaerobic Fermentation	336
89	Design Characteristics for Lagoons (779a, 670) (after (312a))	344
90	Composition of Synthetic Sewage Media Used by Pipes (815)	350
91	Characteristic Parameters (after El-Baroudi and Moawad (323))	355
92	Some Lagoon Design Practices	360
93	Values of θ for Some Lagoons	361
94	Performance Data for Lagoon Treatment of Dairy Wastes	369
95	Aerated Lagoon Performance as Reported in the Industrial Survey	374
96	Maximum Application Rates for Water as Recommended by United States Soil Conservation Service (1166a)	377
97	Recommended Applications of Dilute Waste per Irrigation (1 in. = 22,600 gallons per acre)	378
98	Content of Mineral Matter and Nitrogen in Milk and Its Products and By-products (after 677)	382
99	Performance Data for Spray Irrigation Systems	393

LIST OF TABLES (Continued)

Table No.		Page
100	Operational Characteristics of Five Spray Irrigation Systems (after Lawton, et al., 191, 612, 613)	396
101	Performance Data for Ridge and Furrow Irrigation	397
102	Waste Treatment Costs for Commercial Dairy Food Plants in 1970	403
103	Operating Costs for the Installation of Various Treatment Methods for Dairy Food Plant Costs (1966 Dollars) (355)	409
104	Cost of Dairy Food Plant Waste Water Treatment	410
105	Capital Cost for the Installation of Various Treatment Methods for Dairy Food Plant Costs (1966 Dollars) (355)	411

SECTION I

CONCLUSIONS

The following conclusions are presented as the major findings of this investigation concerning the current practices and problems of the dairy food industry with relation to wheys and waste water treatment.

1. The dairy food industry has only limited information concerning the waste loads with relation to BOD and suspended solids of its waste water. Statistical evaluation of the data obtained from 624 plants would suggest that information can exist for not more than 20% of the plants of the total dairy food industry. In this particular survey of plants making up 10% of the total plant number and processing more than 50% of the total milk supply, only about 12% of these operations had knowledge of their BOD load.

2. Knowledge of waste load could be directly related to (a) recent citation by a governmental agency for violation of current ordinances and/or standards; (b) payment of a surcharge on BOD and/or compositional factors; and (c) operation of their own treatment facility. The operation of treatment facilities, however, did not insure knowledge of BOD in the raw or treated wastes.

3. Less than 1% of the dairy plants surveyed had compositional data on their waste water beyond BOD and/or suspended solids.

4. Only two plants have made a specific attempt to develop a materials balance for their operation to identify the specific sources of waste water volume and BOD sources.

5. The waste water strength of the majority of the dairy plants was found to be higher than that incurred from previous studies and from previous literature. The value in parts per million BOD_5 ranged from 40-10,000, with an average for all dairy plants of about 2500 parts per million. Generally, the suspended solids is about one-fourth to one-third of the BOD level.

6. COD, recommended previously as a preferred method of analysis, was not being used by the dairy food industry. Those who had used the procedure had abandoned it as being less reliable and providing less information than BOD. Evaluation of BOD to COD ratios revealed that dairy food plant wastes frequently have BOD to COD ratios of less than the 0.5 expected from the milk constituents only. Values as low as 0.1 BOD to COD ratios were found and were correlated to detergents and/or sanitizers. Specific compounds contributing to this toxicity could not be identified.

7. Limited information was obtained from the fat, protein, carbohydrate and mineral content of dairy food plant wastes.

8. Detergents may be a significant factor in dairy food plant wastes in the following ways: (a) can contribute up to 200 parts per million BOD to a waste water, (b) can contribute up to 40% of the total waste water volume, (c) certain materials appear to be toxic, (d) surfactants can be present in concentration from 5-20 parts per million, which would be sufficient to have a depressing effect on K_{LA}, and (e) contribute significantly to sodium and phosphate levels of the dairy plant waste water.

9. Sanitizers can contribute to BOD, consist of 5% of the total waste water, contribute up to 200 parts chlorine to the waste water, and may contain toxic materials.

10. Waste water that has been treated by biological means containing less than 20 parts per million BOD may contain up to 250 parts per million COD. The inference of information obtained suggests that the COD can be attributed primarily to refractory organic materials present in detergents, sanitizers, and, possibly, in lubricants.

11. The waste water volume and strength can be expressed best in terms of waste water volume coefficients and BOD coefficients in terms of the amount of milk or milk equivalent processed, rather than in terms of product produced. Waste water volume coefficients were calculated in terms of pounds per pound of milk processed and BOD_5 coefficients in terms of pounds of BOD per thousand pounds of milk processed.) Under good operations, these coefficients were essentially numerically equivalent. When wheys from buttermilk are eliminated from waste water, the coefficients for various types of plant operations appear to be similar with differences between plants of the same type being greater than differences between various types of dairy food plants.

12. Normal waste water coefficients appeared to be between 0.5 and 3.0 for both waste water volume and BOD in terms of per pound and per thousand pounds of milk process, respectively.

13. No relationship could be found between the level of technology and BOD and waste water volume coefficients. Indeed, the highest coefficients were frequently found in high capacity plants that had been automated in terms of fluid processes and CIP.

14. The factors most directly correlated to waste water coefficients were management attitude and management practices. Under good management, it seemed that waste water volume coefficients of one and BOD coefficients of one pound per thousand pounds of milk processed can be achieved in most instances.

15. Whey is the most visible single source of BOD in dairy food operations, followed by wash water from cottage cheese operation (8 pounds per thousand pounds of milk processed), the start-up changeover and shut-down of HTST units (0.5 pound of BOD per thousand pounds of milk processed) and rinsing of dairy food plant equipment (0.2 pound per

thousand pounds of milk processed for milk and up to 1.5 pounds per thousand pounds product processed for cultured products and ice cream).

16. Over 90% of the fluid dairy food plants utilize municipal treatment facilities.

17. Increasingly, practice is being made of BOD surcharge. These charges range from one to five cents per pound of BOD and one to five cents per pound of suspended solids with the average surcharge running about two to two and a half cents per pound of BOD or suspended solids.

18. There is a increasing tendency for municipalities to set strength limits on waste water which are acceptable for being transferred to the treatment facility. These are frequently at the level of municipal sewage and do not appear to be able to be met by dairy plants at the present time. If this trend continues throughout the country, a number of dairy food plants will have to consider the construction of a separate treatment facility.

19. The treatment of fluid dairy food plant wastes can be achieved by aerobic biological oxidation means with spray irrigation, activated sludge, trickling filters and aerated lagoon systems being most commonly employed. At least six spray irrigation systems have been forced to discontinue in the last year because of odor problems and because they are not applicable to the high wash strengths in a number of large dairy plant operations.

20. Only limited information is available concerning the design parameters such as treatment kinetics, cell yields, cell degradation, cell response to nutrient, oxygen availability and temperature, that are needed for the intelligent design and operation of dairy food plant waste treatment facilities. Substantially more data is available for activated sludge and trickling filters than for other potential treatment methods.

21. The microflora of dairy food waste treatment facilities appear to be different from that of most municipal systems because of the chemical composition and the high organic load. Under ideal conditions Pseudomonad, and Arthrobactor would dominate. Under less sufficient aeration, Sphaerotilus, Beggiatoa and Bacillus become the dominant microflora. Where shock loading occurs or loads are consistently high in whey solids, molds and yeasts become the dominant organisms.

22. Activated sludge treatment plants on dairy wastes do not provide for good characteristic sludge. Problems are met continually with floating sludge and for sludge deflocculating in passing over the clarifier. Waste treatment facilities in which over 50% of the BOD comes from milk solids, or over 10% of the BOD comes from whey, take on the typical characteristics of dairy wastes in respect to microflora and in respect to operating characteristics. Wash water from cottage cheese creates a

problem in activated sludge systems by inducing foaming and causing a necessary oxygen input. The oxygen requirement for dairy wastes are higher than for municipal wastes. This may be attributable to detergents. Major problems in the treatment are high loads, and lack of uniformity of volume and strength.

23. Trickling filter treatment systems have been used with some success for treatment of dairy wastes including some whey, or whey wash water. Ponding and sensitivity to high BOD or NaCl strengths have been reported. Recent systems use dilution, medium- to high-rate recirculation, media with large void dimension, flexible series rough filtration--perhaps even alternating double filtration, followed by final filtration, clarification, sludge beds and lagoons. Most of such applications have been in Great Britain. The primary source for kinetic and stoichiometric data come from a single study of simulated combined dairy-whey and domestic waste, rather than actual dairy, or dairy-whey waste.

24. The available data for anaerobic digestion, lagoons, especially, the faultative and anaerobic domains, and land disposal are primarily limited to grass performance data acquired in the mid-1950's. Relatively little data is available on the kinetics, or yields of these systems.

25. The operational problem reported with dairy treatment systems suggest that treatment facilities need to have sufficient capacity and to be staged to give satisfactory effluents in spite of reasonable variation in loadings and biological treatment efficiency.

RECOMMENDATIONS

Current research on dairy wastes and dairy waste treatment is rather limited in the United States. Most of the work currently in progress or recently completed involves demonstration grants centered primarily around the area of whey recovery and utilization, and demonstration grants for the determination of the efficiency of various treatment systems. Essentially no basic research is in progress in this country at the present time sponsored by the Water Quality Office that relates specifically to dairy wastes and their treatment. There is a considerable amount of research in progress sponsored by a wide variety of agencies in regard to development of new methods and procedures for whey utilization. Research needs based on this investigation are as follows:

1. Inventory of dairy food plant waste waters. There is a need to undertake, on a broad industry basis, a statistically sound investigation aimed at determination of the waste water volume and waste concentration in terms of BOD, COD, and suspended solids for dairy food plant waste to determine if the limited information (less than 20%) is applicable to the entire industry

2. Determination of the chemical composition of dairy waste waters and factors affecting composition. Information is needed not only in respect to BOD, COD, and suspended solids, but also regarding lipid, protein, carbohydrates, and mineral constituents present in dairy food plant waste water, the factors which affect marked variations in the ratios of the various constituents and the significance of this to waste water treatment.

3. Determination of a material balance for various types dairy food plants with emphasis on highly automated large operations. This should include a complete accounting of all in-coming and out-going materials of the plant and the specific contribution of each unit process to waste water volume, BOD, COD, and chemical composition.

4. Information is needed to determine the significance of detergent, sanitizers and lubricants in dairy food plant waste waters. Research is needed to establish completely the specific chemical compounds being utilized, their concentrations, their effect on BOD_5, BOD_U, COD, mass transfer of oxygen and efficiency of treatment.

5. Fundamental information is needed concerning the metabolic state and factors affecting the rate of biological degradation of the various constituents of dairy food waste, particularly emphasis on carbohydrate, protein, and lipid. The specific state of each constituent needs determining and the influence of constituents or variations of these constituents on the polysaccharides and lipid content of the bio-mass needs to be established.

   The metabolic state of lactose vs. milk protein appears to reoccur in various forms--in aerated lagoon - activated sludge foam and high sludge yield, low endogeneous resination sludge setting problems for anerobic digesters, lush shock-sensitive trickling filters, slimes, and loss of infiltration capacity of soils.

6. If detergents are found to be significant factors in dairy food plant waste waters, research is needed to develop new methods of cleaning to either eliminate undesirable chemical compounds and/or to materially improve the efficiency of cleaning to reduce the concentration of such compounds in dairy food plant waste waters.

7. There is need to determine exactly why whey and/or cottage cheese wash water which contains about 25%-50% of the solids of whey, have such deleterious effect on biological oxidation. In this regard, the specific significance of whey proteins, lactic acid and sodium lactate need to be determined.

8. The evaluation of biological oxidation at high BOD and COD levels needs to be further investigated with particular concern to develop optimal kinetic constants for utilization design of waste treatment facilities.

9. A demonstration project is needed to determine the extent to which milk solids can be excluded from dairy plant waste waters and to establish optimum procedures and minimal costs for such systems. This should include the utilization of existing automated systems to provide optimal control in segregation of high solids dairy wastes.

10. To develop procedures for segregation of high solids wastes, and concentration of these materials for utilization in food or feed. In this regard, there is need for development of new types of membrane for reverse osmosis units which would not clog in the presence of casing. Present reverse osmosis units are nonoperative on milk waste containing casing. Developing of nonfouling membranes would permit the economic utilization of reverse osmosis to other dairy food plant systems other than whey.

11. Continued research in developing new methods for processing and marketing whey.

12. Research to develop an optimum educational program to convince dairy food plant management that it is economical and desirable to control dairy food plant wastes.

13. An integrated investigation of alternate treatment systems to obtain better information on the advantages and limitations of the various treatment methods on a single waste source.

SECTION III

INTRODUCTION

The gross national product of the United States is enriched by the dairy industry to the extent of about 12.9 billion dollars per year, which accounts for about 16% of the contribution of the total food industry to the nation's economy. General trends in the country indicate the dairy industry will continue over the next several decades to be a significant contributor to the economy of the country. The trend over the last several years for reduced milk production appears to be reversing and the amount of product being processed has actually increased from 103.9 billion pounds in 1960 to 108.4 billion pounds in 1969, whereas the total production of milk on the farm changed from 123.1 billion pounds in 1960 to 116.2 billion pounds in 1969.

The dairy foods industry has long been recognized as a significant contributor to stream pollution. About 10 years ago a United States Senate committee singled out the dairy industry as the second most important single source of stream pollution. Cheese manufacture and the resultant whey production, which approximates 21 billion pounds per year, has been the largest single visible source of pollution potential. The continued growth of the cheese industry and the inherent problems of economically utilizing whey results in a continued need to develop innovative ways to eliminate whey as a pollutant. The recent attention to phosphate pollution also focuses attention on the dairy industry because of its relatively high usage of phosphate-containing cleaning compounds.

This investigation was undertaken to determine the state-of-the-art of dairy waste and the treatment of these industrial wastes. Special attention has been directed to: (1) an evaluation of industry trends that have potential significance to the future role of dairy food plant wastes on the environment, (2) determination of the extent of knowledge of the dairy food industry on their waste loads and methods for implant control of wastes, (3) a detailed search of the world's literature relating to all aspects related to dairy food plant wastes, including the compilation of a comprehensive bibliography and the evaluation and interpretation of the significant literature, (4) an evaluation of the body of unpublished knowledge held by industrial dairy food companies in relation to waste loads, current problems and future needs, (5) determination of current research in progress and, (6) examination of research needs relative to dairy food plant wastes.

To accomplish the objectives of the investigation, the study was approached in two broad ways: (1) a search of the world literature on dairy food plant wastes, preparation of an annotated bibliography and an interpretive review of the literature and, (2) survey of industry knowledge and practices through personal contact wherever possible, and

Preceding page blank

through limited site visitations to selected operations. In the course of the latter, particular attention has been given to the larger modern plant operations which have been increasing in significance in recent years and which will continue to dominate the industrial dairy food picture in the future.

For the purpose of this report information obtained from literature search and from industrial surveys will be integrated to the greatest extent possible in order to provide a more coherent understanding of the total state-of-the-art.

SECTION II

SIGNIFICANT INDUSTRIAL TRENDS

TRENDS IN THE NATURE AND STRUCTURE OF THE DAIRY FOOD INDUSTRY

Trends which have significance to the nature of dairy wastes and waste treatment include, (a) the marked decrease in the number of dairy plants and increased production per plant, (b) changes in the relative production of various types of dairy foods with different levels of waste loads, (c) automation of plant processes to an increasing degree with increasing plant size and consolidation, and (d) a shift in the location of new plant facilities.

Changes in Dairy Plant Size and Product Volume per Plant: Over the past 20 years there has been a marked change in the number and size of many types of dairy food plants. For cheese and butter plants, a marked decline in plant numbers occurred prior to 1948. For fluid milk plants, there was a decrease of about 75% in numbers between 1948 and 1958. Ice cream plants showed a similar decline. In the past decade, the decline in plants has been exponential, showing a linear semi-log relationship as illustrated in Figure 1. Based on these past trends projected changes in plant numbers up to 1983 are indicated also. Assuming that the numbers of plants will continue to decrease at a declining rate, the annual decline in plant numbers for various operations can be projected for the next thirty years as follows:

Type of Plant	Decline in Number of Plants Per Year, %
Cheese	3.9
Ice cream	6.0
Evaporated and condensed milk	4.0
Fluid milk	5.56
Cottage cheese	6.6
Butter	6.2
Dried milk	4.80

The increase in daily production for various plants is illustrated in Figure 2 for the past 20 years, and the predicted growth in plant production is projected to 1983. The relative rate of growth of daily production per plant for butter, cheese, dried milk, evaporated milk and milk are essentially similar, whereas the growth in production of the plant for cottage cheese will occur at about double the rate for other types of dairy product operations. The production of cottage cheese whey per plant is predicted to exceed the per plant production of sweet whey by 1974.

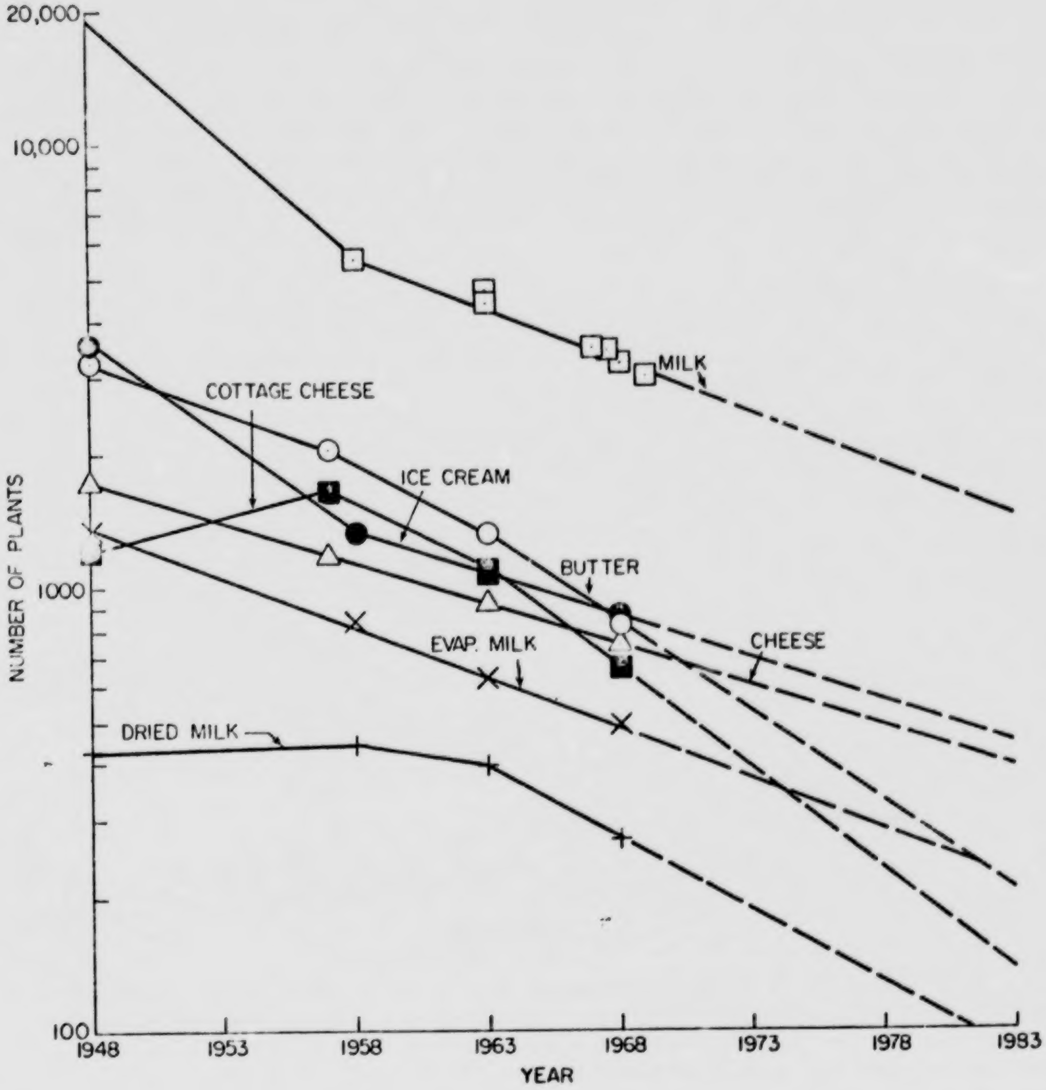


Figure 1 - Past and projected trends in the number of various types of dairy plants in the United States

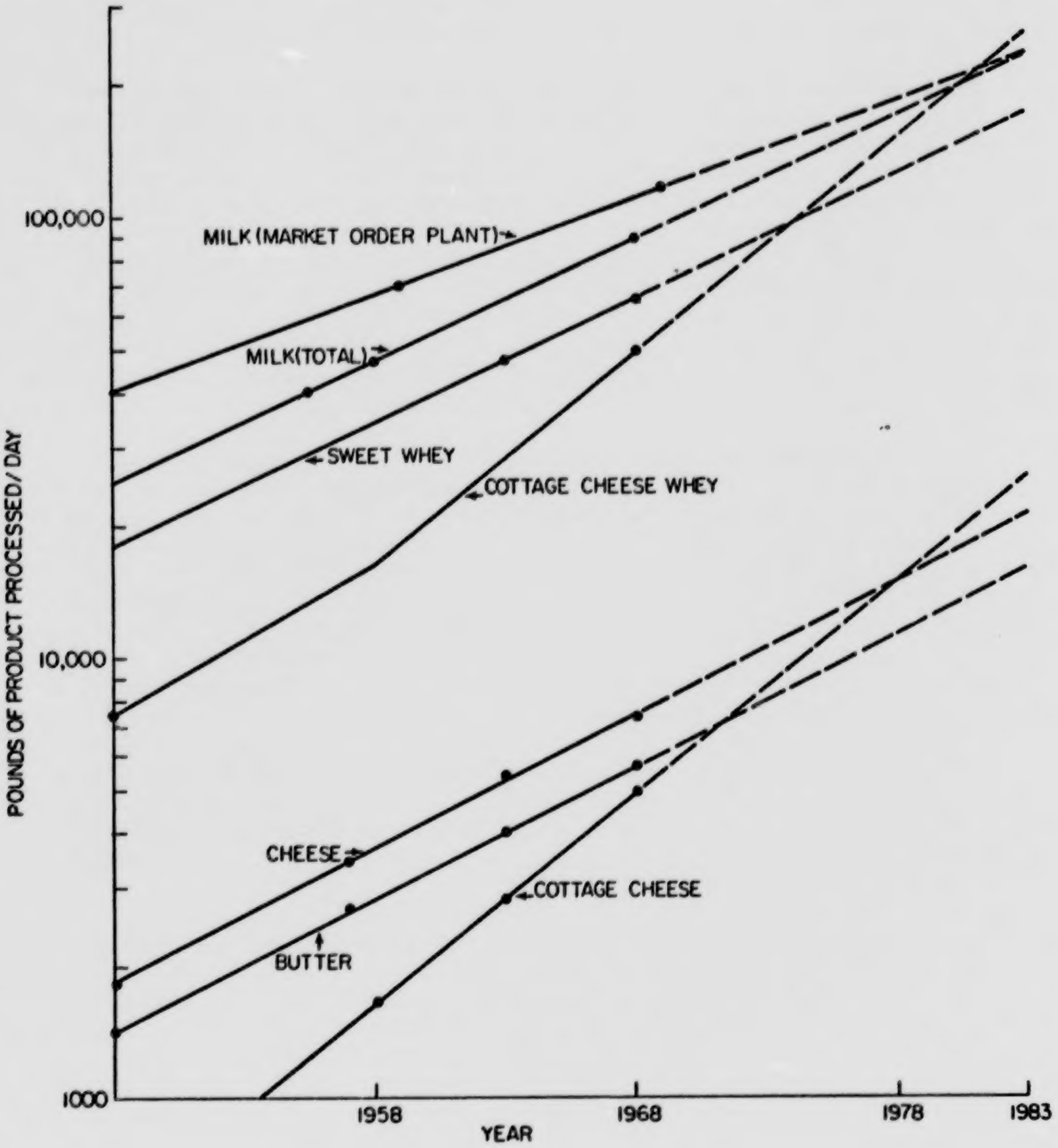


Figure 2 - Past and project production per day for various types of dairy plants in the United States

In 1969 the total amount of whey produced was approximately 21 billion pounds with about 6 billion pounds being acid whey. These figures are based on calculated whey volumes from the USDA figures for cheese production. USDA figures for whey production were 17 billion pounds and would appear to be based on incomplete reporting.

Whey has long been the most visible pollutant of the dairy food industry. The potential significance of whey and the magnitude of the problem facing the industry in eliminating this material as a waste product is illustrated by the fact that about 20% of the total milk produced in the country is converted into whey at the present time. The very magnitude of the volume of whey contributes materially to the problem. Cottage cheese whey represents a more serious problem than sweet whey because of its acid nature which limits its utility as a food or feed. Of special concern is the more than 6 billion pounds of cottage cheese wash water approximating 70,000,000 pounds of BOD. The solids are too dilute to recover economically, and the wash water creates problems in waste treatment which will be detailed later in the report.

At the present time, the fluid milk plants, which operate under various Federal Milk Market Order systems and handle about 50% of the fluid milk volume, average over 100,000 pounds of milk per day. This could be expected to increase to about 225,000 pounds per day by 1983. Technologically, maximum plant size appears to be unlimited, but specific limitation on plant size in the future includes: (a) procurement problems associated with bringing milk long distances, (b) the problems of distribution over long distance, (c) manageability of large, complex plants, (d) control of waste loads, and (e) local sanitary district regulations and taxation policies.

Using projected changes in plant numbers and production per plant, the total projected production of various dairy products between 1970 and 1985 is projected in Figure 3. The values predicted for 1977 are in general agreement with those projected in the Cost of Clean Waters Waste Profile No. 9 (355).

The projection presented in this report assumes that the trends of the past decade will continue into the future. In this regard it is important to point out that those segments of the dairy food industry that are potentially the greatest environmental polluters are also those segments of the industry showing the most growth potential. These sub-industries, cottage cheese, cheese, and ice cream are the only segments of the overall dairy industry to show increases in per capita consumption for the past decade.

Processing Changes: As plants become larger in the future, there will be greater utilization of mechanization and automation in all phases of dairy food plant operations. Waste profile No. 9 in 1967 (355) adequately outlined the types of dairy food processes and indicated the differences in old, typical and advanced technology. The larger plants

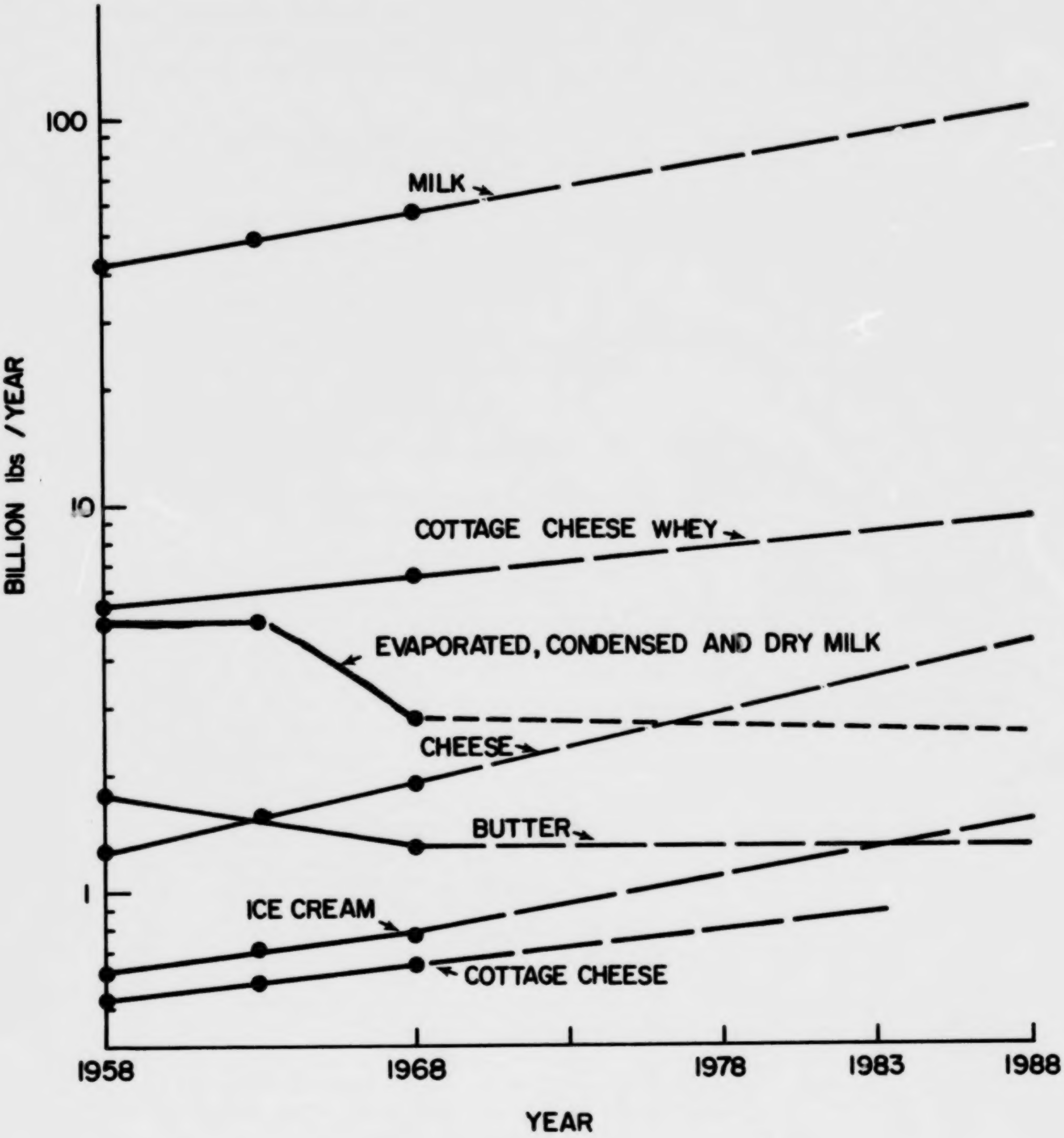


Figure 3 - Past and projected annual production of selected dairy foods in the United States

today and those of the future will rely upon advanced technology, and automation will be the center of this technology. Key advanced technologies applicable to all types of dairy food plants that has significance to dairy plant waste loads include:

(a) Milk receiving in tank trucks with automated rinsing and cleaning of the tankers at the dairy plant.

(b) Automated dairy food processing operations processing milk at rates up to 100,000 pounds/hr, including the use of Cleaned In Place separators and clarifers that automatically discharge sludge every 15 to 30 minutes.

(c) Automated circulation cleaning, using liquid detergents and chemical sanitizing agents on a controlled basis.

(d) High speed filling and packaging operations.

(e) Automated materials handling, using conveyors, casers and stackers requiring significant quantities of lubricants.

Theoretically, advanced technology should reduce water volumes used in dairy food plants and provide for reduced waste loads. Waste Profile No. 9 indicated that BOD waste coefficients (#BOD/#product) became less with the use of advanced technology, with plant size having no effect on waste coefficients. As will be reported in later parts of this report, however, the use of advanced technology in itself is no guarantee of low waste coefficients. Some possible explanations include:

(a) The assumption on the part of management that automation negates the need to pay attention to wastes.

(b) Single use of cleaning compounds in large volumes.

(c) Complexities and increased product loss in filling and conveying operations.

(d) Increase use of lubricants on cases, stacks and conveyors with automated materials handling.

(e) Increased amount of product that can be left in lines (a 1-1/2 million pound milk plant may have lines with a capacity up 8 to 10,000 pounds of product).

(f) Increased concentration of waste with more efficient water usage.

Trends in Plant Locations: As dairy food plants become larger, they have a greater need to be located in an area that provides for optimum access to major highways. The tendency is to locate these large plants near interstate highways in suburban areas, frequently in small to medium-sized cities.

The trend is for dairy plants to service a larger and larger area, trucking in raw milk from considerable distances and hauling out packaged products in semi-trailers as many as 500 miles from the processing plant. The independence of the plant location from closeness to the market has resulted in the trend to locate new large plants in suburban areas, some distance from any major waste treatment facility.

Frequently, little attention has been given to the problem of waste disposal as a key criteria in the location. A number of new plants, discharging up to 8,000 pounds of BOD per day, have been located in suburban areas or in cities of under 50,000 population. Where such plants utilize the municipal waste treatment facility they can become the major contributor to the BOD load of the municipal system.

The trend towards larger, centralized dairy foods plants generating 2,000-10,000 pounds of BOD per day, will frequently place an additional burden on municipal treatment plants that may already be marginal in their operation. The average milk plant of 1980 (250,000# milk/day) can be predicted to have waste loads with a population equivalent of about 55,000 unless special effort is made to pretreat and/or markedly reduce these wastes.

SECTION III

DAIRY FOOD INDUSTRY'S KNOWLEDGE TOWARDS WASTE LOADS AND WASTE TREATMENT

Industry Knowledge of Waste Loads: An effort was made to assess the knowledge of the dairy industry in respect to the technology of fluid wastes and waste treatment, to determine the extent of knowledge the industry has of its waste loads in terms of BOD, COD, and suspended solids, and to ascertain the attitude of the industry towards waste and waste prevention.

Contacts were made with the management of the 18 largest proprietary dairy companies and the 10 largest farm cooperatives processing dairy foods to ascertain their knowledge of the waste loads of the plants which they operated. Attention was centered on knowledge of BOD in plant waste discharges as an index of knowledge of waste loads. Information was also obtained concerning the use of waste composition as a basis for sewage surcharges and information concerning dairy plant treatment of their own wastes to determine the relationship of these factors to knowledge of waste loads. Information was obtained from all of the proprietary organizations and all but three of the cooperatives. In addition, the same information was obtained for 234 independent dairy plants in Alabama, Illinois, Indiana, Iowa, Kentucky, Massachusetts, Michigan, Missouri, New York, Ohio, Pennsylvania, Tennessee and Wisconsin. In all, 647 plants were included in the survey (about 10% of the total dairy plants in the country). Although precise figures cannot be obtained, the plants represented processed more than 65% of all the milk sold off the farm in 1969.

The information in respect to the knowledge of waste loads, number of plants paying surcharge on either BOD or suspended solids, the number of plants which either have their own treatment facility, and the number of plants discharging untreated wastes to municipal sewer systems, is summarized in Table 1. The information is divided into three categories: national or regional proprietary companies, local proprietary companies and major dairy cooperatives operating processing plants. Overall, the knowledge of BOD concentration in waste water was about 11%. Statistical analyses, on the basis of the available data, shows that the knowledge of waste loads (for the total industry) could not exceed 20% at a 1% confidence limit. Thus, it would appear that the knowledge of waste water BOD loads in the dairy food industry is small and is insufficient to provide a true index of the total BOD and SS from the nations dairy food industry that requires waste treatment at this time. In six instances where initial surveys for BOD and SS were made while this study was in progress, the values obtained were 1.5 to 10.0 times the values for other plants in the same organization for which BOD and SS values had been known for some time.

Table 1 - Summary of Knowledge of Dairy Food Plant Loads by Dairy Food Firms

	Proprietary Companies	No. of Plants	Knowledge of Waste Loads No.	Knowledge of Waste Loads %	Surcharge on Waste Composition No.	Surcharge on Waste Composition %	Plants Treating Own Waste No.	Plants Treating Own Waste %	Discharge to City No.	Discharge to City %
National and Regional	A	32	0	0	0	0	7	21.8	25	78.1
	B	35	2	5.7	2	5.7	1	2.8	35	100
	C	9	4	44.4	2	22.2	0	0	8	88.8
	D	19	3	15.7	2	10.5	1	5.2	18	---
	E	75	3	4	2	2.6	1	1.3	74	98.6
	F	10	2	20	0	0	2	20	7	70
	G	15	2	13.3	1	6.6	1	6.6	13	86.6
	H	12	1	8.3	1	8.3	0	0	12	100
	I*	5	5	100	0	0	1	20	4	80
	J	11	0	0	0	0	0	0	11	100
	K	8	0	0	0	0	0	0	8	100
	L	27	6	22.2	1	3.7	6	22.2	22	81.4
	M	20	2	10	0	0	3	15	18	90
	N**	7	6	---	---	---	3	---	4	---
	O	15	2	2	2	13.3	1	6.6	14	93.3
	P	5	2	40	2	40	0	0	5	100
	Q	15	1	6.6	1	6.6	2	13.3	14	93.3
Local Proprietary Companies		234	28	11.9	20	8.5	16	6.8	224	95.7
Cooperatives										
	R	9	1	11.1	0	0	4	44.4	---	---
	S	5	0	0	0	0	0	0	---	---
	T	1	1	100	0	0	1	100	---	---
	U	27	1	3.7	5	18.5	3	11.1	---	---
	V	21	0	0	0	0	0	0	21	100
	W	7	0	0	0	0	0	0	7	100
	X	23	3	13	3	13	2	8.6	20	86.9
Total		647	75	11.5	44	6.8	55	8.6	564	87.1

*Recently closed two plants after municipalities imposed surcharge on BOD and suspended solids.

**Incomplete information on selected operations; percentages not calculated.

Reproduced from best available copy.

At the same time, caution must be employed in interpreting the extent of waste load knowledge for various plants. Frequently, the information available is on the basis of a single survey and only a limited number of plants have information of waste loads on a continuing basis. The industry as a whole appears to be in a very vulnerable position, and no firm statement on the composition of dairy wastes can be made on an industry-wide basis at this time.

Companies differ widely in respect to their knowledge of waste loads of their various plants. Companies operating more than one processing plant had knowledge of BOD values ranging from 0 to 100%. The organization having 100% knowledge was an exception, having as a key administrator an individual with research experience in dairy wastes. Generally, the proprietary companies are better informed than the cooperatives about their waste composition (12.8% to 6.4%, respectively). The regional supermarket companies that have become a market force in the past decade generally have more knowledge of waste loads than more established firms because they have built their plants at a time when states and communities were more waste conscious. Generally, where plant age was known, knowledge of waste loads was about four times greater in plants built since 1960 than for plants built previously. The major factor would appear to be that these are larger plants in small cities and suburbs with a much more visible waste load.

Overall, 87% of the plants discharged their waste waters to municipal treatment plants and 9% treated their own wastes. About 80% of the plants paid a surcharge on waste water volume, whereas only 7% paid a surcharge on BOD or other waste composition factors.

The breakdown of knowledge of waste loads by various segments of the dairy food industry is presented in Table 2. Information concerning categorization of plants by the types of products manufactured was available for 445 of the 647 plants surveyed. Four hundred and four of these plants discharged wastes to municipal treatment plants, 34 treated their own wastes, 43 paid a surcharge on BOD levels and 72 had knowledge of the BOD_5 in their waste waters. One hundred and seventy four (39%) of the plants processed more than one type of dairy product in the facility.

Table 3 gives the percentages distribution of different types of dairy plants in respect to knowledge of BOD_5 loading in reference to BOD_5 surcharges and treatment by city or plant. Over 75% of all types of plants discharged wastes to municipal sewer systems except for concentrated milk plants which had the highest percentage (41%) of its own treatment plants. Generally, milk, ice cream, milk and ice cream combination and milk, ice cream and cottage cheese plants had treatment facilities for less than 5% of the plants. Knowledge of BOD values in plant wastes varied as a function of the type of plant involved. Knowledge of BOD loads was between 20% and 30% for milk and ice cream, cheese and concentrated milk plants; between 10% and 20% for milk and cottage

Table 2 - Summary of Dairy Food Plant Waste Knowledge by Plant Type

Type of Operation	No. of Plants	No. of Plants Discharging Waste to City	No. of Plants With Knowledge of BOD Loading	No. of Plants With Treatment Facilities	No. of Plants Paying Sur-Charge on BOD
Milk	143	138	14	5	13
Ice Cream	26	26	2	0	2
Cottage Cheese	11	8	3	2	0
Conc. Milks	22	13	10	9	0
Milk Powder	16	12	2	4	4
Ripened Cheese	53	40	18	13	0
Milk and Ice Cream	21	21	5	1	6
Milk and Cottage Cheese	43	42	8	2	9
Milk, Ice Cream and Cottage Cheese	51	49	5	1	5
Milk and Other Products	59	55	5	4	4
Total	445	404	72	34	43

Table 3 - Percent Knowledge of BOD

Type of Operation	No. of Plants Discharging Waste to City, %	No. of Plants With Knowledge of BOD Loading, %	No. of Plants With Treatment Facilities, %	No. of Plants Paying Surcharge on BOD, %
Milk	96	9.8	3	9
Ice Cream	100	8.3	--	8.3
Cottage Cheese	75	12.5	12.5	--
Conc. Milks	59	4.5	40.9	--
Milk Powder	75	12.5	25	25
Cheese	75.0	24.4	22.4	--
Milk and Ice Cream	100	25	5	30
Milk and Cottage Cheese	97.6	16.6	4.7	19
Milk, Ice Cream and Cottage Cheese	96	9.8	1.9	9.8
Milk and Other Products	93.2	8.4	6.7	6.7
Total	90.8	15.9	9.0	9.8

cheese; cottage cheese and milk powder plants; and less than 10% for milk; ice cream; milk, ice cream, and cottage cheese; and milk and other product plants.

In all instances where there was knowledge of the waste load, one or more of the following criteria were met:

(a) Plant operated its own treatment plant.

(b) Plant was paying a surcharge on the basis of waste composition.

(c) Plant had been cited by a government agency for violation or had been notified to reduce waste loads to a specific level by a specific time.

However, the operation of a waste treatment facility by the plant did not ensure that the plant management knew the waste loads going into the treatment facility. This was true for 16 separate plants or 18% of those operating waste treatment facilities. One company operating several treatment plants indicated that, "No BOD or SS solids measurements are made of raw or treated waste water. The efficiency of the treatment plants are determined by visual inspection."

In all but one of the plants, those plants paying a surcharge on BOD levels knew the BOD_5 values for their plant wastes. Generally, BOD analyses for surcharges were made on a quarterly 3-7 day survey on a corrected volume basis. In a few instances grab samples were used and charges were being made in several cases on the basis of values obtained over two years earlier.

Industry Attitudes to Waste and Waste Treatment: The evaluation of attitudes is more subjective than determination of knowledge of waste loads and was evaluated on the basis of conversations with hundreds of dairy industry people during the course of this investigation. Overall, the attitude of the industry can be classified as passive. At the recent Dairy and Foods Exposition in Houston, Texas, an excellent program on pollution and its control was attended by less than 75 people, while over 10,000 industry representatives were only a few steps away. Almost without exception, those industry representatives attending the sessions were those who met the criteria for plants having waste load knowledge.

Generally, the industry knows that the problem will have to be faced, but has not taken the initiative in solving the problem and with a few exceptions it would appear the industry will not take remedial steps until forced to do so by legal or economic pressures. During the course of the study the investigators have been told by several industry representatives not to indicate the lack of knowledge or the magnitude of waste loads in the industry with the expressed hope that "the problem will go away if you don't keep it stirred up."

A major reason for the passiveness of the industry is economic. Because of low profit margins, the expenditure of funds for noneconomic returns has been avoided. The industry has not yet accepted the premise proposed by Stein in 1968 (1057) that the dairy industry must "begin considering water pollution control as an integral cost of doing business, like any other production item." Other reasons for the industry's attitude are (a) lack of knowledge of the nature and strength of dairy plant wastes, (b) failure to understand the potential economic value in reducing wastes and converting them to economically valuable by-products and (c) lack of understanding of the technology of waste control and treatment. Numerous members of the industry not currently involved with operating waste treatment facilities or paying surcharge on BOD or SS have no understanding of BOD, could not differentiate between BOD_5 and BOD_U and had never heard of COD. As municipalities increase the practice of charging industry for its wastes on a compositional basis and/or impose legal limits on waste composition, the industry will take a more active role in fluid waste control. Where such practices are in operation, industrial management have become concerned and active. Frequently, however, they lack the essential knowledge to deal effectively with the problem.

An active nationwide educational program is needed to influence attitudes and to provide a sound technological basis for controlling the pollution problems of the dairy industry of the future.

SECTION VI

DAIRY PLANT WASTES

Industrial wastes from dairy plants consist primarily of varying quantities of water-borne milk solids from a variety of sources, detergents and sanitizers, lubricants and domestic wastes. The quantity and strength of the waste water discharged from the dairy food plants will vary widely depending upon the quantity of water utilized, the control of management over various waste discharges and the type of processing operations. This section of the report shall cover waste composition, waste volumes and various sources of organic fluid wastes in dairy plant operations.

Waste Composition: Information concerning the composition of dairy food plant wastes has been obtained both from literature and from industrial sources. In some areas more information is available from industrial sources than is currently available from the literature. Prior to quite recently, the majority of information in respect to dairy food plant wastes has been limited to BOD, COD and suspended solids. Only limited information is generally available for pH, free fat and other components such as phosphates, chloride and sulfur.

The Biological and Chemical Oxygen Demand of milk plant wastes will vary as a function of the products manufactured, since differences occur in the amount of oxygen required for the oxidation of different milk constituents such as fat, carbohydrates and protein. Various dairy products vary widely in their relative concentrations of major organic constituents and an understanding of the composition of the various fluid dairy foods is essential to full understanding of dairy plant wastes. The constituents of primary concern in water pollution for various dairy products are cited in Table 4. These values are based upon current average compositional values and vary somewhat from previously cited compositional data for dairy products in earlier waste guides (262, 265, 265a). These data include mineral constituents and viscosity values not previously cited. Mineral values provide an index of the potential significance of milk constituents to water hardness (Ca and Mg) and phosphate and chloride pollution. The viscosity of the various dairy products is important since the amount of product remaining on equipment surfaces after draining will vary inversely as a function of viscosity. Whey-cheese conversion factors are presented in Table 5 for various types of cheese. The values provide the basis for converting pounds of cheese and/or cheese curd to whey solids and fluid whey.

Table 4 - Average Composition of Milk and Milk Products (100 g)

Product	Fat (g)	Protein (g)	Lactose (g)	Lactic Acid (g)	Added Organic Ingred.	Total Organic Solids	Ca (mg)	P (mg)	Cl (mg)	S (mg)	Total Ash (g)	Viscosity (c.p. at 20°C)
Skim Milk	0.08	3.5	5.0	--	--	8.56	121	95	100	17	0.7	1.4
2% Milk	2.0	4.2	6.0	--	--	12.2	143	112	115	20	0.8	2.4
Whole Milk	3.0	3.5	4.9	--	--	13.1	118	93	102	19	0.7	2.2
Half & Half	11.7	3.2	4.6	--	--	19.5	108	85	90	16	0.6	7.5
Coffee Cream	18.0	3.0	4.3	--	--	25.3	102	80	73	12	0.6	15.0
Heavy Cream	40.0	2.2	3.1	--	--	45.3	75	59	38	9	0.4	25.2
Choc. Milk	3.5	3.4	5.0	--	Sucrose, 6% Choc.Solids, 1%	18.5	111	94	100	19	0.7	75
Churned Buttermilk	0.3	3.0	4.6	0.1	--	8.0	121	95	103	15	0.8	1.5
Cultured Buttermilk	0.1	3.6	4.3	0.8	--	10	121	95	105	17	0.7	500
Sour Cream	18	3.0	3.6	0.75	--	24.6	102	80	73	12	0.6	10,000
Yoghurt	3.0	3.5	4.0	1.1	Fruits, Flavors	10.5	143	112	105	19	0.7	9,000
Evaporated Milk	8.0	7.0	9.7	--	--	27	757	205	210	39	1.6	30
Ice Cream	10.0	4.5	6.8	--	Sugar, 15%	41.3	146	115	104	20	0.9	35.0
Whey (sweet)	0.3	0.9	4.9	0.2	--	6.3	51	53	95	8	0.6	1.4
Cottage Cheese Whey (acid)	0.08	0.9	4.4	0.7	--	6.1	96	76	95	8	0.8	1.3

Table 5 - Whey — Cheese Conversion Factors

Cheese	Milk		Yield*				Whey Solids		Fluid Whey	
			Curd		Whey					
	Type	% B.F.	Lb.	% H_2O	Lb.	% Solids	Per 1 lb. Curd	Per 1 lb. Cheese	Per 1 lb. Curd	Per 1 lb. Cheese
Cheddar	Whole	3.5	9-1/2	35	90-1/2	6-1/2	0.618	0.618	9.56	9.56
Cottage Conventional	Skim	0.1	15	80	72	6.1	0.293	0.202	4.80	3.37
Creamed	Cream	10.5	33	54-1/2	67	6.0	--	0.122	--	1.99
Parmesan	Skim	1.8	8-3/4	41	91-1/4	6-1/2	0.678	--	10.42	--
	Skim	1.8	7-1/2	32	--	--	--	0.79	--	12.1
	Skim	1.8	6-1/4	17	--	--	--	0.95	--	14.6
Swiss	Whole	2.8	8	38	92	6-1/2	0.746	0.746	11.50	11.50

*Yield based on 100 lb. milk with fat content shown under milk column.

BIOLOGICAL OXYGEN DEMAND (BOD)

BOD for Various Dairy Products

Literature Values: Numerous investigators have reported on the Biological Oxygen Demand for various fluid dairy foods (7, 159, 201, 239, 262, 335, 475, 523, 616, 889, 1133, 1164). Major emphasis in the literature has been placed on the BOD_5 value. The majority of the experimental values presented in the literature predate 1960 and the original citations generally do not refer specifically to methodology used. A further complication in the full interpretation of literature values is that numerous papers provide a citation for BOD values for various dairy products without any indication of the source for their information (335, 889, 1238, 1273). Percentage of organic solids, ranges and average BOD_5 values, pounds of BOD_5 per pound of organic solids and calculated ultimate BOD values are presented in Table 6 for various major fluid dairy foods. Average BOD_5 values range from 67,000 for skim milk to about 400,000 for 40% cream.

The ratio of pounds of BOD_5 to pounds of organic solids is an indication of the relative completeness of biological oxidation in five days for the various products. The ratios for skim milk, whole milk, cream and ice cream mix are essentially the same, ranging from 0.82 to 0.88. Less complete oxidation is indicated for concentrated milk, churned buttermilk and sweet whey.

It should be pointed out that those products with the highest BOD_5 values, such as cream and ice cream mix, also constitute those products with the highest viscosities and, therefore, the most difficult to drain from lines and processing equipment. High viscosity products for which BOD_5 values are not available in literature, and which are becoming increasingly significant in fluid dairy plant operations, include buttermilk, yoghurt and sour cream. It would be expected that the BOD_5 values would approximate those of the products from which they are manufactured, skim milk, whole milk and cream, respectively. However, the ratio of BOD_5 to BOD_U would be expected to be more like that of whey, than of the non-acid starting materials.

Industry Values: Additional BOD_5 values were obtained either from municipal treatment facilities or from industrial dairy plant laboratories utilizing standard methods of analysis and are tabulated in Table 7. These data provide BOD_5 information for products for which there is no information in the literature or where literature values are limited. Values are presented for half and half cream, coffee cream, whipping cream, ice cream mix, whey from cheddar cheese and Italian cheese operations, cottage cheese whey and filtered cottage cheese whey. The values for half and half cream, coffee cream and whipping cream are as expected in the ratio of pounds of BOD_5 to pounds of organic solids similar to that of concentrated milk. The whey values from cheddar cheese and Italian cheese operations are within the ranges reported. The values

Table 6 - Literature Values for BOD of Various Dairy Products

Product	Percent Organic Solids	BOD_5 (ppm) Range	BOD_5 (ppm) Average	BOD_5 lb/lb Organic Solids	BOD_U* (ppm)
Skim Milk	8.2	40,000- 73,000	67,000	.82	82,000
Whole Milk	11.7	84,350-125,000	104,635	.88	117,000
Half & Half	18.2	-	-	-	182,000
Cream - 18%	23.7	-	-	-	232,000
Cream - 40%	44.9	399,000	399,000	.88	449,000
Concentrated Milk (2:1)	26.2	208,000	208,000	.79	262,000
Ice Cream Mix (10% fat)	34.0	292,000	292,000	.85	340,000
Churned Buttermilk	6.8	55,000- 72,000	51,600	.75	68,000
Whey (sweet)	6.0	25,000-120,000	33,889	.56	60,000

*Assuming 100% oxidation of all organic matter

Table 7 - Industrial BOD_5 Values for Selected Dairy Products*

Product	Reported BOD_5 by				Average	Average lb BOD_5/lb Organic Solids
	A	B	C	D		
Half & Half	130,000	160,000	150,000	--	146,000	0.81
Cream - 18%	220,000	190,000	210,000	--	206.000	0.89
Cream - 40%	460,000	400,000	380,000	--	413,000	0.90
Ice Cream Mix (10%)	440,000	380,000	350,000	400,000**	392,500	1.1
Whey	60,000	44,000	37,000¶	--	47,000	0.78
Cottage Cheese Whey	42,000	40,000	65,000	70,000	54,250	0.90
Filtered Cottage Cheese Whey	33,000	--	30,000	--	31,500	0.52

* Reported by various industrial firms, based on BOD_5 determined by Standard Methods

** Nut ice cream mix

¶ BOD_U for this sample reported as 65,000 ppm for various cottage cheese wheys range from 40 to 70 thousand parts/million, whereas the filtered cottage cheese whey values range from 30 to 33 thousand. Therefore, the cottage cheese whey figures reflect varied concentrations of fine casein particles and would reflect variations in manufacturing procedures.

BOD_5 for Various Milk Constituents and Related Components

Values for BOD_5 for various milk constituents have been determined in a limited number of investigations (390, 453, 572, 705) ranges and average values are presented in Table 8, along with values for surfactants and hydrocolloids used in dairy food manufacture. Average values of pound BOD_5/pound component were 0.65, 0.89 and 1.03 for lactose, milk fat and milk proteins, respectively. Reported values for lactose ranged from 0.42 to 0.72, with the lowest values being found for 5% lactose concentrations and the highest value being reported for 0.1% lactose concentration. Wide ranges of values have been reported also for milk fat and milk proteins, as well as related compounds. The factors affecting these variations are not readily apparent from the literature.

Table 8 - Reported BOD Value for Various Milk Constituents and Related Constituents

Constituent	Pound BOD_5/Pound Component		BOD_{20}
	Range	Average	
Lactose	0.42 - 0.72	0.65	0.89
Glucose	0.53 - 0.78	0.66	1.01
Lactic Acid	0.63 - 0.64	0.63	0.88
Milk Fat	0.70 - 0.95	0.89	-
Glycerol	0.65 - 0.83	0.75	0.98
Butyric Acid	0.34 - 0.90	0.75	-
Sodium Butyrate	-	0.41	-
Palmitic Acid	-	1.07	-
Sodium Palmitate	0.4 - 1.02	0.70	-
Stearic Acid	-	0.80	-
Sodium Stearate	0.45 - 1.70	1.20	-
Milk Proteins	0.60 - 1.20	1.03	-
Casein	0.25 - 1.17	1.04	-
Hydrocolloids			
Sodium Alginate	-	0.36	-
Carboxymethyl-cellulose	-	0.30	-
Surfactants			
Soap	1.41 - 1.47	1.43	-
Dreft	-	0.49	-
br. ch. Alkyl Benzyl Sulfonate	-	0.02	-
Tween 80	-	0.35	-

The full significance of the BOD_5 ratios requires an understanding of the relationship of these values to theoretical oxygen requirements for the given compound. Only limited data are available for milk constituents.

Theoretical oxygen requirements for total oxidation vary as a function of the component. Adolf-Fritz (374) reported theoretical O_2 values for lactose and its components along with calcium lactate and the amino acid leucine. The theoretical BOD values, BOD_5 and BOD_{40} values as percentage of theoretical oxygen utilization are presented in Table 9. In theory one pound of lactose would require 1.06 pound of oxygen, whereas 1 pound of calcium lactate would require 1.9 pound of O_2. For carbohydrates, the completeness of biological oxidation was greatest for glucose, next for galactose and least for lactose. For the compounds studied, leucine gave the lowest efficiency value.

Table 9 - Percentage of Theoretical Oxygen Utilization by Pure Compounds

Substrate 1000 mg	Theoretical O_2 mg/100 mg	Percentage of Theoretical Oxygen Utilization		
		COD (KCr_2O_3)	BOD_5	BOD_{40}
Glucose	969	100	61	100
Galactose	1066	100	47	100
Lactose	1066	100	18	55
Ca Lactate	1880	100	62	84
Leucine	1466	42	0.75	1.2

The average reported values for BOD_5 were utilized to calculate the BOD_5 values of various fluid dairy foods. The calculated and average reported values for selected dairy foods are presented in Table 10. The calculated BOD_5 values are in good agreement with the reported values. Thus, the values of the individual components can be used to determine the BOD_5 value for any fluid dairy food of known composition. In addition, analyses of dairy food plant wastes for milk components will permit an accurate estimation of the relative significance of milk solids in the total BOD_5 of the waste.

The calculated percentage contribution to BOD_5 by milk constituents in various dairy food products in Table 10 provides an insight into possible differences in waste treatment requirements for wastes from different types of dairy plants.

Table 10 - A Comparison of Literature and Calculated BOD$_5$ Values and Percentage Contribution of Milk Components to Product BOD$_5$

Product	Literature BOD$_5$	Calculated BOD$_5$	% Contribution to BOD$_5$ by:			
			Milk Fat	Milk Protein	Lactose	Lactic Acid
Skim Milk	67,000	73,000	6.3	49.3	44.5	--
2% Milk		100,000	17.8	43.3	39.0	--
Whole Milk	104,000	99,000	31.5	36.4	32.2	--
Half & Half	156,000	167,000				
Coffee Cream	206,000	219,000	73.1	14.1	12.8	--
Heavy Cream	399,000	399,000	89.2	5.7	5.0	--
Choc. Milk	--	145,000	21.5	24.2	22.4	--
Churned Buttermilk	68,000	71,000	4.2	48.2	46.7	.98
Cultured Buttermilk	--	64,000	1.3	52.2	39.4	7.1
Sour Cream	--	218,000	73.5	1.4	10.7	21.7
Yoghurt	--	91,000	27.8	37.6	27.1	7.2
Evaporated Milk	208,000	206,000	34.6	35.0	30.6	--
Ice Cream	292,000	290,000	30.7	15.9	15.2	--
Whey	34,000	45,000	5.9	20.6	70.8	2.8
Cottage Cheese Whey	31,500	42,000	1.6	22.1	68.1	10.5

BOD_5 and Waste Water Volume Coefficients for Commercial Dairy Food Plant Wastes

The strength of dairy food plant waste waters is frequently reported in ppm of BOD, without regard to total waste water volume or the relationship to the amount of milk processed, whereas waste volumes are reported irrespective of the volume of product processed. Early investigators soon recognized that a definite relationship existed between the amount of milk received and the pound of BOD_5 in the waste waters (174, 276, 328, 428, 1110, 1124). However, there remains the tendency to use ppm BOD_5 as the index of waste strength and in some instances ppm of a specific component is set as a limit without regard to the total load.

Investigations cited in the literature for BOD values and waste water volumes for dairy plant operations are cited in the Bibliography Annotation.

Waste volume and strength as a function of milk processed and/or product produced will be referred to as "waste coefficients." Where more than one type of product is manufactured in a single plant, coefficients are valid only in terms of the amount of milk processed, since the waste streams from the separate operations are not segregated and vary widely in both volume and strength. Where data for the amount of milk processed, type of plant, ppm BOD and volume of waste water are available, waste coefficients can be calculated from the raw data.

Coefficients of BOD_5 and waste water volume as a function of the amount of milk processed and/or product produced are useful for determining the significance of dairy wastes, for determining current dairy plant waste loads, for basic data needed for design of treatment facility either by the dairy plant or by joint efforts of the municipalities, and for evaluating the efficiency of various dairy food plants. However, little attention has been given to such coefficients until recently (338, 355, 385, 467, 938, 1206, 1228). Coefficients have been reported either in respect to pounds of product produced or pounds of milk processed.

Literature Values: Literature coefficients for BOD_5, expressed as pounds/1000 pounds of product, are summarized in Table 11. The data reported from Waste Profile No. 9 are taken from the examples used in the comparative cost analyses, since they seem to be in best agreement with other values. Except for condensed milk, the coefficients calculated from the figures used in the comparative cost analyses are not in agreement with those presented in tabulated form. For a given product, the BOD coefficients are in general agreement for different investigators, with the variations being within day-to-day variations that have been observed for individual plant operations. The lack of attention given ice cream plant operations in the past is apparent in the fact that values are available only from Waste Profile No. 9. The ice cream plant coefficients are lower than for any other type of dairy plant and may

Table 11 - Reported Pollution Coefficients for Dairy Plant Waste in Pound BOD_5/1000 Pounds Product Produced

Product	Wagner (1950)	Average Pollution Coefficients - Pound BOD_5/1000 Pound Product					
		RAAD (1950) Netherlands	Hoover & Jasewicz (1965)	Scheltinga* (1966)	Profile 9 - (1967)		
					Old Tech.	Typical Tech.	Advanced Tech.
Milk Receiving	1.05	0.52	--	0	--	--	--
Market Milk	--	2.8	1.0	--	2.9	1.1	0.6
Butter	30.0	15.0	--	7.7**	50.3	39.2	35.6
Cheese	30.0¶	14.0¶	23.6	29.5¶	41 ¶	19 ¶	11 ¶
Cottage Cheese	--	--	16.5	--	12.3¶	8.8¶	2.2¶
Powdered Milk	10.5	14.0	26.4	19.9	--	--	--
Condensed Milk	3.5	3.5	2.25	5.2	6.8	5.1	4.1
Ice Cream	--	--	--	--	1.6	0.6	0.3

* 30% of the industry will have waste coefficients in excess of 2.5 times values given
** Continuous churn
¶ Excludes whey

reflect reflect an operation limited to the production of bulk ice cream mix, since plant survey figures presented later in this report are considerably higher than these reported coefficients.

The coefficients vary markedly between products, with variations being in the area of 20- to 60-fold depending upon the investigator. The lowest coefficients are for ice cream, milk receiving and milk processing, and the highest values are for butter and cheese. Both butter and cheese values are exclusive of either buttermilk or whey. The variations between products reflect differences in the amount of milk processed per pound of product produced, rather than a marked difference in BOD as a function of product.

With standard milk equivalents for the various products, waste coefficients in terms of BOD_5/1000 pounds of milk processed were calculated and the results presented in Table 12. This type of expression of BOD coefficients eliminates much of the apparent variation between different types of dairy plants and suggest that this coefficient may be more universally applicable in expressing dairy food plant waste strengths. As reported by Walholz (1204), the countries surveyed by the International Dairy Federation favor reporting waste volume coefficients in terms of units per standard unit of milk processed. On this basis, the overall variation reported for any type of milk plant operation ranged from 0.1 to 4.1 pounds of BOD_5/1000 pounds of milk received.

Waste water volume coefficients from the literature expressed in terms of pounds of waste water/pound of milk received and pounds of waste water/pound of product produced are summarized in Table 13 for different types of dairy plants. Average coefficients range from 1.2 pounds/pound of milk received for fluid milk processing plants to 5.8 for ice cream. The International Dairy Federation reports a waste water volume coefficient in terms of pound/pound of milk processed or received as ranging from 0.5 to 2.5. The large values given in the ranges probably reflect the inclusion of cooling water.

Limited data are available which provide coefficients for cooling water and all other waste water for some different types of dairy plants (821, 1286, 1287). These are summarized in Table 14. Cooling water coefficients ranged from 1 to 24.9, with an overall average of about 12.5 pounds/pound of milk processed, whereas all other waste waters ranged from 0.3 to 9.1 with an average of 1.5. Re-use of water in dairy plants is relatively low, ranging from 0 to 10%. Increasing recycling of water could reduce the waste volume coefficient to less than 0.5 for all types of dairy plant operation.

The only study to report both waste water volume coefficients and BOD_5 coefficients was presented in Waste Profile No. 9 (355). The coefficients presented in tabular form are not in agreement with those calculated from the information provided in the comparative cost analyses, except for the condensed and evaporated milk data. The data for waste

Table 12 - Reported Pollution Coefficients for Dairy Plant Waste in Pound BOD_5/1000 Pounds Product Produced

Product	Wagner (1950)	Average Pollution Coefficients - Pound BOD_5/1000 Pound Milk Received*					
		RAAD (1960) Netherlands	Hoover & Jasewicz (1966)	Scheltinga (1966)	Profile 9 - 1968		
					Old Tech.	Typical Tech.	Advanced Tech.
Milk Receiving	1.05	0.52	--	--	--	--	--
Market Milk	--	2.8	1.0	--	2.9	1.1	0.6
Butter	1.4	0.7	--	0.32	2.3	1.8	1.6
Cheese	3.0	1.4	2.3	2.9	4.1	1.9	1.1
Cottage Cheese	--	--	2.6	--	2.0	1.4	0.35
Powdered Milk	1.4	1.8	3.5	2.6	--	--	--
Condensed Milk	0.4	0.4	0.9	2.2	2.8	2.1	1.7
Ice Cream	--	--	--	--	0.6	0.2	0.1

* Based on milk equivalents as follows:
butter - 21.3 lbs. milk
cheese - 9.9 lbs. milk
cottage cheese - 6.25 lbs. milk
milk powder - 7.4 lbs. milk
ice cream - 2.7 lbs. milk
condensed milk - 2.4 lbs. milk
non-fat dry milk - 11.0 lbs. milk

Table 13 - Waste Volume Coefficients for Dairy Plant Wastes

Product	No. of Reports	Pounds Waste Water/ Pounds Milk Received		Pounds Waste Water/ Pounds Product	
		Range	Average	Range	Average
Butter	15	0.7 - 8.8	2.4	14.9 - 187.4	51.1
Cheese	22	0.5 - 5.1	1.75	4.9 - 50.5	17.3
Milk	18	0.2 - 18.6	3.7	0.2 - 18.6	3.7
Condensed Milk	6	1.2 - 14.5	5.0	2.8 - 33.5	11.0
Condensed Milk less Cooling Water	3	0.8 - 2.0	1.2	1.8 - 4.6	2.8
Milk Powder	10	0.8 - 11.5	2.0	7.2 - 99	18.0
Ice Cream	3	4.2 - 8.4	5.8	11.3 - 22.8	15.6
All Dairy Products	110	0.2 - 18.6	3.5	--	--

Table 14 - Significance of Cooling Water in Dairy Food Plant Waste Water

Investigator	Year	Product	Pounds Waste Water/Pounds Milk Provided		
			Cooling Water	All Other	Total
Platen	1945		1.1	0.3	1.4
Zack	1952	Receiving	--	.8 - 1.6	.8 - 1.6
Zack	1952	Milk	3.3 - 4.9	5.8 - 9.1	9.1 - 13.3
Zack	1956	Condensed	9.1 - 18.2	0.9 - 3.5	12.0 - 23.5
Zack	1956	Cheese	--	.9 - 2.8	0.9 - 2.8
Zack	1956	Curd & Powder	16.6 - 24.9	1.4 - 1.8	18.0 - 26.7
Zack	1956	Curd	8.3 - 16.6	2.5 - 3.3	10.7 - 19.9
Zack	1956	Curd, Powder, Ice Cream	10.0 - 14.9	1.2 - 1.6	11.2 - 16.3
		All Products	1 - 24.9	0.3 - 9.1	0.8 - 26.7

water volume, pounds of BOD and pounds of product given in the cost analysis sections for various types of operations were used to calculate waste coefficients, both in respect to the amount of product produced and the amount of milk received (or processed). Since there was no difference in the coefficients of plants of different sizes, only the data for medium-sized operations were tabulated, as presented in Table 15.

The volume coefficients ranged from 0.5 for cheese plants to 14.5 for condensed and evaporated milk plants with an overall average of 4.9 pounds of waste water per 1000 pounds of milk processed. The BOD coefficient ranged from 0.3 to 43, with an overall average of 5.0 pounds of BOD_5 per 1000 pounds of milk received, irrespective of the technology employed. For all types of dairy food plants, the average waste coefficients for typical technology were 4.8 and 3.7 for volume and BOD, respectively.

Waste water volume coefficients and BOD coefficients were correlated, with a correlation coefficient of 0.79. With changes in technology, both volume and BOD coefficients decreased as technology changed from old to typical and from typical to advanced. With the exception of condensed and evaporated milk plants, changing from typical to acvanced technology reduced waste volume coefficients by about 100%. The same was true for the BOD coefficients, except for condensed milk and butter plants, where the reduction in BOD coefficients were less than 50%. Generally, the differences between typical and advanced technology as cited include: (a) installation of total CIP (cleaned in place) piping in place of partial CIP piping, (b) automatic packaging in place of partially automatic packaging, (c) automatic materials handling rather than partially automatic materials handling, and (d) utilization of continuous rather than batch processing for butter and ice cream. It is difficult to visualize how these changes can affect the reported savings in waste water and BOD coefficients.

Available literature values for milk receipts, waste water volumes and BOD_5 values in ppm were utilized in the calculation of waste water volume and BOD coefficients. A year long survey of 56 Danish dairy plants is presented in Table 16. Waste water coefficients ranged from 0.44 to 6.4 and BOD coefficients ranged from 0.07 to 3.8. Data for other studies are presented in Table 17 and include the investigator, year of report, type of technology, milk received per day, and daily waste water volume, waste water per 1000 pounds of milk received, waste water per 1000 pounds of product produced, ppm and pounds of BOD and waste coefficients for BOD in respect to both milk received and product produced. All investigations prior to 1953 were classified as old technology, since bulk tank handling of milk, continuous processing and CIP were not being used except in a very few operation. The waste load in pounds of BOD/day ranged from 0.6 to 15,720 pounds for a whey drying operation. BOD strength in ppm varied widely, also, ranging from 28 to 11,330. Eighteen of the 46 values exceeded the 1500 ppm BOD that is

Table 15 - Calculated Waste Coefficients from Waste Profile No. 9 (355)

Investigator	Products	Pounds Milk Received	Gal. Waste Water/Day	Pounds Waste Water/Pounds Milk Received	Pounds of Product	Pounds Waste Water/Pounds Product	BOD ppm	Pounds BOD	Pounds BOD/ 1000 Pounds Milk Rec'd	Pounds BOD/ 1000 Pounds Product
Waste Profile No. 9	Cheese-old tech.	33,600	6,500	1.6	3,400	15.9	2576	139	4.1	40.8
Waste Profile No. 9	Cheese-typ. tech.	33,600	4,100	1.0	3,400	10.0	1939	66	2.0	19.4
Waste Profile No. 9	Cheese-adv. tech.	33,600	2,100	0.5	3,400	5.1	2157	37.6	1.1	11.1
Waste Profile No. 9	Butter old tech.	83,070	44,070	4.4	3,900	94.0	6535	196	2.3	50.2
Waste Profile No. 9	Butter adv. tech.	83,070	17,200	1.7	3,900	36.6	1070	153	1.8	39.1
Waste Profile No. 9	Condensed-old. tech.	110,880	194,000	14.5	46,200	34.8	195	315	2.8	6.8
Waste Profile No. 9	Condensed-typ. tech.	110,880	162,000	12.1	46,200	29.1	175	236	2.1	5.1
Waste Profile No. 9	Condensed-adv. tech.	110,800	144,000	10.7	46,200	25.8	158	190	1.7	4.1
Waste Guide No. 9	Ice Cream-old tech.	10,813	11,000	8.4	4,005	22.8	69	6.3	0.58	1.6
Waste Guide No. 9	Ice Cream-typ. tech.	10,813	6,400	4.9	4,005	13.6	43	2.3	0.21	0.6
Waste Guide No. 9	Ice Cream-adv. tech.	10,813	5,500	4.2	4,005	11.3	31	1.4	0.12	0.3
Waste Guide No. 9	Milk & Cottage Cheese (10%)	44,400	36,500	6.8	--	--	6311	1912	43	--
Waste Guide No. 9	Milk & Cottage Cheese (10%)	44,400	19,600	4.3	--	--	3080	502	11.3	--
Waste Guide No. 9	Milk & Cottage Cheese (10%)	44,400	15,300	2.9	--	--	2134	271	6.1	--

Table 16 - Waste Coefficient for Various Dairy Plants in Denmark (1236)

Plant No.	Milk Record Pounds/Day	Pounds Waste Water/Day	Waste Water Coefficient Pounds/Pounds Milk	Pounds BOD	Pounds BOD/ 1000 Pounds Milk	Product Code*
7	10266	55440	0.66	14.96	1.46	MB
14	49870	57200	1.14	21.9	0.43	BC
17	58800	133430	2.26	17.8	0.30	M
24	72700	153340	2.10	67.0	0.92	MBC
32	31530	74030	2.34	27.3	0.86	MBC
36	33730	69410	2.05	30.2	0.89	(surplus milk)
41	45470	105380	2.31	89.6	1.97	BC
53	41070	38610	0.94	23.5	0.57	MBC
63A	37400	34650	0.92	9.8	0.26	MBC
64	63070	85470	1.35	12.0	0.19	B
66	51330	184690	3.59	40.0	0.77	C
78	46200	51040	1.10	157.4	3.26	MB
84	40330	219120	5.43	11.8	0.29	BC
88	44000	17930	0.40	45.5	1.03	BC
91	46200	153340	3.30	39.6	0.85	MB
92	30800	91410	2.97	22.3	0.72	MBC
96	49130	147180	2.99	39.2	0.79	BC
97	38130	83270	2.18	148.5	3.88	BC
104	30070	49280	1.65	16.8	0.55	BC
106	40330	57860	1.43	76.9	1.90	C
107	27130	57970	2.13	20.4	0.75	(surplus milk)
109A	78470	141350	1.80	28.0	0.35	BC
112	49870	22220	0.44	9.7	0.19	B
114A	30800	14740	0.47	2.4	0.07	MBC
118	35200	229020	6.50	45.0	1.27	BC
120	56470	240790	4.26	125.6	2.22	MBC
122	52070	36850	0.75	20.9	0.39	BC
124	58700	189750	3.23	41.9	0.60	B
130	46200	53900	1.16	67.3	1.45	MB
132	58700	138270	2.35	20.3	0.34	B
133A	29330	94710	3.22	30.4	1.03	BC
134	44730	121660	2.71	19.7	0.44	MB
135	27130	150260	5.53	26.7	0.98	C
136	22000	44000	2.00	6.7	0.30	MB
137	49870	147180	2.95	16.1	0.32	B
139	44000	44550	1.01	65.7	1.49	BC
144A	36670	63580	1.73	29.0	0.79	MBC
147	40330	108460	2.63	17.3	0.40	C
149	105600	398970	3.77	57.6	0.54	BC
152	73330	197120	2.68	88.3	1.20	B
154	27870	60610	2.17	8.3	0.30	BC
155	26400	59180	2.24	22.5	0.85	MBC
157	51330	194480	3.78	27.3	0.53	BC
159A	40330	30470	0.75	84.6	2.09	MB
162	22000	45320	1.96	4.9	0.22	(surplus milk)
166	36670	38390	1.04	16.9	0.40	BC
168 day	293330	1375880	4.69	948.0	3.23	BC
169	31530	84260	2.67	99.2	3.14	C
170	22730	101970	4.48	63.0	2.77	BC
173A	60870	63690	1.04	121.4	1.99	C
174	40330	135080	3.33	154.5	3.83	BC

*M = Milk; B = Butter, C = Cheese

Table 17 - Dairy Plant Wastes - BOD_5, Waste Volume, and Waste Volume Coefficients

Investigators	Product	Technol.	Year	Pounds Milk Received/Day	Gal. Waste Water/Day	Pounds Waste Water/Pounds Milk Received	Pounds Product Produced	Pounds Waste Water/Pounds Product	BOD_5 ppm	BOD_5 Pounds	Pounds BOD_5/ 1000 Pounds Milk Rec'd	Pounds BOD_5/ 1000 Pounds Prod. Produced
Lawton	Cheese	T	1959	20,500	4,300	1.7	2,070	17.24	4790	171	.83	8.2
Lawton	Cheese	T	1959	10,600	1,135	0.9	1,070	8.8	4310	40.6	3.8	37.9
Lawton	Cheese	T	1959	20,000	1,170	4.8	2,020	4.8	1260	12.4	0.62	6.1
Lawton	Cheese	T	1959	13,500	380	0.3	1,363	2.3	936	2.9	0.21	0.8
Lawton	Cheese	T	1959	33,500	5,900	1.5	3,384	16.9	1400	8.2	0.24	2.4
Watson	Cheese	T	1960	121,000	61-75,000	4.1 - 5.1	12,222	40.8	381-609	189-463	1.6 - 3.8	15.5 - 37
Royal	Cheese	A	1964	80,000	12,500	1.3	8,080	12.8	1300	163	2.0	12.0
Neil	Cheese	T	1948	132,000	16,000	1.0	13,300	10.1	1931	255	1.9	19.1
McKee	Cheese	T	1950	52,200	7,600	1.2	5,270	11.9	1984	125	2.4	23.6
McKee	Cheese	T	1950	130,000	15,600	1.0	13,130	9.8	2015	260	2.0	19.8
McKee	Cheese	T	1950	71,300	16,500	1.9	7,200	19.0	1226	168	2.2	23.3
Eldridge	Butter	T	1936	1,000	100	8.3	469	17.7	1000	0.83	0.83	0.83
Morgan & Baumann	Butter	T	1957	99,000	17,000	1.4	4,500	31.3	1500	208	2.1	46.2
Eldridge	Evap. and Condensed	O	1936	1,000	150	1.245	435	2.9	800	1.0	1.0	7.4
Watson	Evap. and Condensed	O	1960	255,192	71,700	2.3	110,950	5.3	812	483	1.9	4.4
Eldridge	Dietary Dairy Foods Condensed and Powd.	O	1942	--	60,000	--	--	--	6000	3000	--	--
Grever & Burkett	Condensed and Powd.	T	1969	--	316,800	--	--	--	1475	5000	--	--
Eldridge	Milk Powder	O	1936	1,000	225	1.8	111	16.8	6000	3000	3.0	22.4
Standeven	Milk Powder	T	1962	436,000	44,300	0.83	48,444	7.6	693	255	0.6	5.3

Table 17 - Continued

Investigators	Product	Technol.	Year	Pounds Milk Received/Day	Gal. Waste Water/Day	Pounds Waste Water/Pounds Milk Received	Pounds Product Produced	Pounds Waste Water/Pounds Product	BOD_5 ppm	BOD_5 Pounds	Pounds BOD_5/ 1000 Pounds Milk Rec'd	Pounds BOD_5/ 1000 Pounds Prod. Produced
De Martini, et. al.	Skim Milk Powdered	O	1946	318,000	243,000	6.0	28,909	74.6	1088	2194	6.9	75.9
De Martini, et. al.	Skim Milk Powdered	O	1946	226,000	347,900	1.3	20,545	140.8	1060	3060	6.6	108.8
De Martini, et. al.	Skim Milk Powdered	O	1946	213,000	295,500	11.5	19,364	150.0	1074	2634	12.3	135.7
De Martini, et. al.	Skim Milk Powdered	O	1946	234,700	27,700	1.0	21,336	10.6	444	102	0.4	4.8
De Martini, et. al.	Skim Milk Powdered	O	1946	177,000	37,720	1.8	16,091	16.4	1500	469	2.6	29.1
De Martini, et. al.	Whey Powder	O	1946	359,000	304,800	7.0	29,900	84.6	908	2229	6.2	74.5
De Martini, et. al.	Whey Powder	O	1946	327,100	157,900	4.0	27,260	43.7	865	1133	3.4	37.7
De Martini, et. al.	Whey Powder	O	1946	278,200	169,300	5.0	23,180	60.9	11330	15920	57.2	515
Eldridge	Milk Receiving	O	1936	1,000	150	12.5	1,000	1.25	900	0.9	0.9	0.9
Horton Trebler	Milk Receiving	O	1953	45,000	2,820	4.9	45,000	4.9	209	4.8	4.8	4.8
Horton and Trebler	Milk Receiving	O	1953	39,100	2,700	6.8	39,100	6.8	180	4.0	0.1	0.1
Horton and Trebler	Milk Receiving	O	1953	57,800	3,200	4.6	57,800	4.6	116	3.0	0.08	0.08
Horton and Trebler	Milk Receiving	O	1953	32,200	2,430	6.2	32,200	1.2	31	0.6	0.02	0.02
Horton and Trebler	Milk Receiving	O	1953	38,400	2,890	6.2	38,400	--	28	0.7	0.02	0.02
Eldridge	Milk	O	1936	1,000	225	18.6	1,070	18.6	600	1.1	1.1	1.1
Hauer	Milk	O	1952	119,000	15,000	2.6	119,000	2.6	950	119	1.0	1.0
Hauer	Milk	O	1952	30,000	12,000	3.3	30,000	3.3	3000	308.8	12.3	12.3
Thayer	Milk	O	1953	32,000	8,760	2.2	32,000	2.2	1400	98.9	3.6	3.6
Horton and Trebler	Milk	T	1954	22,000	25,000	9.4	22,000	9.4	1800	475	22.0	22.0

Table 17 - Continued

Investigators	Product	Technol.	Year	Pounds Milk Received/Day	Gal. Waste Water/Day	Pounds Waste Water/Pounds	Pounds Product Produced	Pounds Waste Water/Pounds Product	BOD_5 ppm	BOD_5 Pounds	Pounds BOD_5/ 1000 Pounds Milk Rec'd	Pounds BOD_5/ 1000 Pounds Prod. Produced
Cantinieaux	Milk	T	1954	141,000	25,000	1.5	141,000	1.5	1660	446	3.1	3.1
Kountz	Milk	T	1960	242,000	47,000	1.6	242,000	1.6	1300	445	1.8	1.8
Watson	Milk	T	1960	319,000	61,600	13.1	39,000	13.1	800	554	1.7	1.7
Chipperfield	Milk	A	1970	1,500,000	250,000	1.4	1,500,000	1.4	3750	7862	5.2	5.2
Christenson	Milk Ice Cream and Cottage Cheese	O	1952	550,000	53,000	0.8	--	--	1115	509	0.9	--
Morgan	Milk, Ice Cream and Cottage Cheese	T	1961	15,930	22,000	1.2	--	--	528	96	0.6	--
Morgan	Butter and Milk Powd.	T	1957	200,000	28,000	1.1	--	--	3000	650	3.2	--
Morgan	Butter and By-produc. drying	T	1957	100,000	15,000	1.2	--	--	1350	168	1.7	--
Royal	Butter and Powder	A	1964	250,000	25,000	1.3	--	--	1629	338	1.3	--

commonly referred to as the average BOD of dairy plant wastes. These were generally associated with plants with typical-to-advanced technology operating, processing more than 50,000 pounds of milk a day. The waste coefficients per 1000 pounds of milk received are summarized in Table 18. Irrespective of plant type, the coefficients are 3.2 and 2.8 for volume and BOD, respectively. Generally, where comparisons can be made, the values are within the ranges given for Waste Profile No. 9. However, the overall averages for both volume and BOD coefficients are lower than those presented in Profile 9.

Table 18 - Summary of Literature Values of Waste Water Coefficients*

Products Mfg.	No. of Plants	Waste Volume Coef.		BOD_5 Coefficient	
		Range	Average	Range	Average
Milk Receiving	6	4.6 - 12.5	6.1	0.02 - 4.8	1.0
Milk	11	1.5 - 18.6	4.9	1.1 - 22.0	5.2
Butter	2	1.4 - 8.3	4.85	0.8 - 2.1	1.46
Cheese	12	0.3 - 2.06	2.06	0.2 - 4.1	1.8
Condensed	2	1.2 - 2.3	1.75	1.0 - 1.9	1.45
Powder	10	0.8 - 11.5	2.8	0.6 - 12.3	8.9
Milk Cottage Ch. Ice Cream	2	0.8 - 1.2	1.0	0.6 - 0.9	0.7
Mix. Prod.	5	1.1 - 6.8	1.2	1.3 - 3.2	1.9
Total	46	0.3 - 18.6	3.9	0.2 - 22.0	2.6

*From Table 17, BOD_5 coefficient based on 1000 pounds milk or milk equivalent received.

Industry Survey Waste Coefficients: Through personal contacts and plant site visits, information on dairy plant wastes and waste treatment was obtained using a detailed guide (Appendix 1) as a means of obtaining as much information as possible on the composition of dairy wastes, and methods and efficiences involved in their treatment by the plant or by the municipality serving the plant. Information obtained for 57 dairy plants in respect to milk volume processed, gallons of waste water, ppm of BOD and calculated pounds of BOD/day and daily volume and BOD coefficients are shown in Table 19. All of the plants used either advanced technology or a mixture of advanced and typical technology, with 30 of the 57 plants manufacturing more than one type of dairy product. For this reason, waste coefficients are presented only in relation to the amount of milk processed. Even though relative amounts of different products were known from the survey data, the waste discharges from the different operations were not segregated and waste volumes and BOD loads could not be determined for the different types of operations in a given plant.

Statistical analyses indicated no significant difference in BOD or volume coefficients and type of plant operation, except that the BOD coefficients for plants processing milk, cottage cheese and ice cream had significantly higher BOD coefficients than any other type of operation. Coefficients were not related to plant size or degree of automation. Plants with fully automated product processing and CIP systems frequently had the higher than average volume and BOD coefficients (see plants marked by asterisk, Table 19).

A summary of waste coefficients by plant type is given in Table 20 for the industrial plants surveyed. As compared to the literature data, the volume coefficients are lower and the BOD coefficients are slightly higher.

The wide variability of both volume and BOD coefficients among plants of similar technologies and size and the lack of correlation between waste coefficients suggests that the controlling factor in waste water volume and BOD coefficients is management interest planning and the efficiency of management supervision. Observations indicated that plants with low BOD and volume coefficients, such as Plant No. 1, had good management control, whereas plants that had high coefficients for both BOD and volume also had poor management supervision. The relationship between management practices and waste water coefficients is discussed in detail later in the report.

BOD-COD Interrelationships

The ultimate oxygen demand has been considered by some investigators to be a better measure of the strengths of dairy wastes than BOD_5. The chemical oxygen demand (COD), which approximately measures the total oxygen utilized in the chemical oxidation of all the organic material in the waste, and BOD_{20} values have been found to be in general agreement (466). The 1959 revised guide for dairy plant waste treatment (1165) recommends the utilization of COD in preference to BOD as a means of determining the ultimate biological oxygen demand of the waste. This recommendation was based primarily on work by Porges and Hoover (830, 831) utilizing skim milk as a model for dairy plant wastes. Hoover's and Porges (475) data for skim milk, together with those of Bergman, et al. (159, 160), Waholz (1206), Reynolds (874) and Bloodgood and

Table 19 - Survey of Milk Volume, Waste Water Volume, ppm BOD and Calculated Waste Water Coefficients for Industrial Dairy Food Plants of Varying Types

Plant No.	Product	Lb. Milk Received	Gal. Volume Waste Water	Lb. Waste Water	Lb. Waste Water/ Lb. Milk Rec'd.	BOD, ppm	BOD, Lb.	Lb. BOD/ 1000 Lb.Milk
43	Milk	500,000	6,277	52,100	0.104	2,247	12	0.234
1*	Milk	383,000	20,000	163,000	0.425	700	12	0.30
5	Milk	75,000	50,000	415,000	5.540	--	--	--
42	Milk	143,000	89,800	745,000	5.20	1,500	1,120	7.81
35	Cheese	100,000	20,000	163,000	1.63	1,000	163	1.63
38	Cheese	40,200	28,200	234,000	5.7	168	39	1.0
39	Cheese	--	85,800	711,000	--	1,954	1,390	--
54	Cheese	20,000	5,000	43,000	2.1	1,600	70	3.5
23*	Ice Cream	150,000	100,000	853,000	5.6	3,700	3,156	21.04
24	Ice Cream	60,000	31,000	261,000	4.3	450	117	1.9
25	Ice Cream Sherbet	34,000	3,430	29,000	0.8	2,500	72	2.1
26	Ice Cream	17,000	11,000	91,300	5.36	600	5,478	3.22
27	Ice Cream	51,500	10,000	83,000	1.6	2,000	166	3.2
9	Ice Cream	27,000	2,500	20,800	0.77	3,100	644	2.4
41	Condensed Milk	250,000	30,000	249,000	0.995	185	46	0.184
47	Condensed Milk	750,000	300,000	2,490,000	3.32	4,000	9,950	13.30

Table 19 - Continued

Plant No.	Product	Lb. Milk Received	Gal. Volume Waste Water	Lb. Waste Water	Lb. Waste Water/ Lb. Milk Rec'd	BOD, ppm	BOD, Lb.	Lb. BOD/ 1000 Lb.Milk
55	Butter	426,000	35,000	340,500	0.8	1,000	340	0.85
45	Powdered Milk	120,000	22,000	183,000	1.52	3,000	550	4.58
50	Whey Powder	500,000	36,000	297,000	0.59	40	12	0.0238
49*	Cottage Cheese	300,000	170,000	1,410,000	4.70	2,080	390	1.30
36	Cottage Cheese	30,000	3,000	24,900	0.83	2,200	55	1.83
37	Cottage Cheese	665,000	1,100,000	8,300,000	12.45	5,700	47,300	71.2
66	Cottage Cheese Milk	623,000	60,300	500,000	0.805	2,500	1,250	2.01
10	Cottage Cheese Milk	842,000	110,000	913,000	1.08	3,300	3,040	3.61
28	Cottage Cheese Milk	374,100	25,750	213,000	.57	4,206	895	2.4
15	Cottage Cheese Milk	87,200	2,450	20,300	0.233	--	--	--
18	Cottage Cheese Milk	208,000	35,000	290,000	1.4	2,863	831	4.0
19	Cottage Cheese Milk	116,100	14,115	116,300	1.00	3,000	349	2.0
29	Cottage Cheese Milk	166,000	42,448	355,000	2.14	925	328	1.98

Table 19 - Continued

Plant No.	Product	Lb. Milk Received	Gal. Volume Waste Water	Lb. Waste Water	Lb. Waste Water/ Lb. Milk Rec'd	BOD, ppm	BOD, Lb.	Lb. BOD/ 1000 Lb.Milk
40	Cottage Cheese Milk	1,000,000	139,200	1,155,000	1.16	3,560	4,120	4.12
48	Cottage Cheese Milk	250,000	30,000	249,000	0.995	--	165	0.66
51*	Cottage Cheese Milk	1,500,000	125,000	1,040,000	0.693	3,120	3,240	2.16
52	Cottage Cheese Milk	465,000	60,000	498,000	1.07	1,700	845	1.82
2	Cottage Cheese Milk, Yogurt	914,000	204,000	1,693,000	1.845	1,225	2,070	2.26
16	Cottage Cheese Milk, Yogurt	487,850	36,200	298,000	0.61	--	--	--
21	Cottage Cheese Milk, Yogurt	415,000	70,000	561,000	1.35	2,970	1,675	4.0
20	Cottage Cheese Milk	309,600	105,000	870,000	2.82	3,600	3,132	10.1
22	Cottage Cheese Milk	95,000	25,000	207,500	2.18	--	--	--
8	Cottage Cheese Milk, Yogurt	1,000,000	250,000	2,070,000	2.07	3,800	8,660	8.66
11	Cottage Cheese Milk	200,000	26,500	220,000	1.32	3,700	815	4.06
12	Cottage Cheese Milk	172,000	38,000	1,240,000	7.22	750	930	5.4
3	Cottage Cheese Milk. Ice Cream	420,000	71,000	589,000	1.405	1,608	950	2.3

Table 19 - Continued

Plant No.	Product	Lb. Milk Received	Gal. Volume Waste Water	Lb. Waste Water	Lb. Waste Water/ Lb. Milk Rec'd	BOD, ppm	BOD, Lb.	Lb. BOD/ 1000 Lb.Milk
17	Cottage Cheese Milk, Ice Cream	60,000	15,700	130,000	2.17	--	--	--
53*	Cottage Cheese Milk, Ice Cream	500,000	150,000	1,245,000	2.49	1,500	1,870	3.74
57	Cottage Cheese Milk, Ice Cream	619,000	--	2,000,000	3.87	3,500	7,200	9.8
30*	Cottage Cheese Milk, Ice Cream	800,000	339,400	2,820,000	3.52	2,168	6,130	7.66
31*	Cottage Cheese Milk, Ice Cream	560,000	100,000	830,000	1.48	3,750	3,110	5.55
32*	Cottage Cheese Milk, Ice Cream	493,000	99,065	822,000	1.67	--	--	--
33*	Cottage Cheese Milk, Ice Cream	621,000	241,000	2,000,000	3.22	4,000	8,000	12.9
34	Cottage Cheese Milk, Ice Cream	880,000	300,000	2,490,000	2.83	3,200	7,900	9.06
7*	Cottage Cheese Cheese, Milk Powdered Milk	620,000	120,000	896,000	1.445	1,700	1,520	2.46
4*	Cottage Cheese Sterile Product	350,000	195,000	1,620,000	4.630	1,500	2,430	6.95
13	Milk, Yogurt	516,000	240,000	1,990,000	3.86	--	--	--
14	Milk, Yogurt	705,000	60,000	558,000	0.79	--	--	--

Table 19 - Continued

Plant No.	Product	Lb. Milk Received	Gal. Volume Waste Water	Lb. Waste Water	Lb. Waste Water/ Lb. Milk Rec'd	BOD, ppm	BOD, Lb.	Lb. BOD/ 1000 Lb.Milk
44	Milk, Butter	300,000	29,000	240,000	0.80	--	260	0.87
46*	Powdered Milk, Butter, Ice Cream	1,500,000	275,000	2,280,000	1.52	1,450	3,320	2.21
56	Powdered Milk, Butter	200,000	60,000	500,000	2.5	1,200	600	3.0

*Plants with automated fluid product processing and CIP

Table 20 - Summary of Commercial Plant Survey for Waste Water Coefficients

Products Manufactured	No. of Plants	Waste Volume Coefficient		BOD Coefficient	
		Range	Average	Range	Average
Milk	6	0.1 - 5.4	3.25	0.2 - 7.8	4.2
Cheese	3	1.63 - 5.7	3.14	1.0 - 3.5	2.04
Ice Cream	6	0.8 - 5.6	2.8	1.9 - 21.4	5.76
Cond. Milk	2	1.0 - 3.3	2.1	0.2 - 13.3	7.6
Butter	1	-	0.8	-	0.85
Powder	2	1.5 - 5.9	3.7	0.02 - 4.6	2.27
Cottage Cheese	3	0.8 - 12.4	6.0	1.3 - 71.2*	34.2
Cottage Cheese and Milk	19	0.5 - 7.2	1.84	0.7 - 8.6	3.47
Cottage Cheese Ice Cream Milk	9	1.4 - 3.9	2.52	2.3 - 12.9	6.37
Mixed Products	5	0.8 - 4.6	2.34	0.9 - 6.95	3.09
Overall	5	0.1 - 12.4	2.43	0.2 - 71.2	5.85

*Whey included

Cannon (176) for skim milk and other fluid dairy products are shown in Table 21 as ratios of BOD_5 to COD. The values of the various investigators are in reasonable agreement for milk, skim milk, and whey.

Table 21 - BOD_5/COD Ratio of Milk Products

Material	BOD_5/COD Ratio				
	Porges & Hoover (1950)	Reynolds (1966)	Waholz (1968)	Bloodgood & Cannon (1942)	Average
Skim Milk	.60	.67	.62	.65	.63
Whole Milk (raw)	.65	.61	.85	.68	.69
Whole Milk (past)	--	--	.84	--	(.84)
Buttermilk (churned)	--	--	.66	--	(.66)
Whey	--	.58	.47	--	.52

Ratios of BOD_5/COD for milk constituents are presented in Table 22. Except for casein, lactose, and lactic acid, only single literature values are available. Where several studies have been made on a given constituent, the ratios are not in close agreement. For example, BOD_5/COD ratios for lactose range from 0.18 to 0.83. Thus, it appears that the efficiency of biological oxidation is variable, with concentration being at least one factor involved. The ratios in relation to lactose concentration are as follows:

Lactose Conc.	BOD_5/COD	Nitrogen Enrichment
0.1%	0.83	Yes
1.0%	0.50	Yes
5.0%	0.18	Yes

Further studies are needed to fully explain the factors affecting the biological oxidation of lactose and milk wastes.

Taking the data of Adolf-Fritz (374), the monosaccharide components of lactose are more readily oxidized than lactose, with the rate of biological oxidation of glucose exceeding that of galactose. Based on limited data, it would appear that whey proteins oxidize slower than casein and all milk proteins are more resistant to biological oxidation than lactose. The significance of these results will be given further attention in the discussion of the biochemistry of dairy food plant waste treatment.

Table 22 - BOD/COD Ratios of Various Milk Constituents and Related Products

Compound	BOD_5/COD Ratios		BOD_U/COD Ratios	
	Range	Average	Range	Average
Lactose	0.18 - 0.83	0.53	0.55 - 1.00	0.75
Glucose	-	0.61	1.00	1.00
Galactose	-	0.42	-	0.82
Sucrose	-	0.56	-	1.00
Lactic Acid	0.40 - 0.62	0.51	-	-
Casein	0.40 - 0.54	0.46	-	-
Whey Protein	-	0.23	-	-
Fat	-	1.28	-	-
Soap	-	0.55	-	-
ABS	-	0.02	-	-

BOD_5 to COD ratios reported in the literature for industrial dairy plant wastes are shown in Table 23. Values vary somewhat widely and are generally less than for the pure milk products themselves, as might be anticipated. Ratios varied between investigators and between the values reported for a given investigator. Overall, the range was 0.11 to 0.80 with an average of 0.53, as compared to a BOD_5/COD ratio of 0.65 for whole milk. Averages among the ten investigators range from 0.33 to 0.66. Values below 0.6 can be interpreted to suggest less efficient biological oxidation of milk wastes than pure milk, probably caused by the presence of non-milk constituents. Apparent "toxicity" of dairy plant wastes is suggested by the values below 0.40, but no reference to possible "toxicity" has been cited in the literature.

Table 23 - BOD_5/COD Ratios for Raw Dairy Plant Wastes

Investigator	Type of Plant	Year	BOD_5/COD Ratios Range	 Average
Hoover & Porges	--	1953	0.34 - 0.80	--
Schulz-Fulkenhaum	--	1955	0.30 - 0.70	--
Waholz	--	1956	--	0.64
Furoff	Multi-product	1960	0.22 - 0.51	0.33
Schweizer	Cheese	1960	0.31 - 0.66	0.45
Rensink	Butter	1962	--	0.66
Christansen	--	1964	0.55 - 0.77	0.64
Walgren	--	1966	0.11 - 0.75	0.47
Bergman, et al.	Multi-product	1966	0.43 - 0.60	0.53
Bergman, et al.	Multi-product	1968	0.40 - 0.75	0.56
Annon	--	1968	0.22 - 0.80	0.35
TOTAL			0.11 - 0.80	0.53

In view of biological oxidation of dairy wastes, Hoover in 1953 (466) reported different ratios at different levels of BOD. Below BOD level of 200 parts/million the ratio was 0.38, whereas from 400 to 900 parts/million the ratio is 0.80 (Fig. 4). The study does not indicate whether the information on low BOD samples was on raw or treated waste. The inference would be, however, that the lower BOD ratio would be from the effluent of waste treatment plants, and the higher ratio is from untreated milk solids, since raw dairy wastes below 500 ppm are seldom reported.

In the course of this investigation, several national and/or regional dairy companies that have had long experience in measuring the strength of dairy plant wastes, indicated that they have attempted to utilize COD but had abandoned the position several years ago because of wide variation in BOD to COD ratios. The apparent lack of agreement of values suggested that the COD value was less reproducible than BOD. Generally, the data from these organizations was no longer available to scrutinize. In one case, BOD to COD ratios were available for the effluent obtained at hourly intervals from one large dairy operation manufacturing milk, ice cream and cottage cheese (Table 24). At the request of the investigators, another survey was made in October of 1970 and these results are given in Table 25. Ratios of BOD_5/COD (Table 24) vary from 0.12 to 0.90 at different periods of the days. The low ratios between 1:00 P.M. and 5:00 P.M. coincided with the major periods of equipment process cleaning. These low values definitely suggest "toxicity." The data in Table 25 also reveal very low BOD_5/COD values over a three-hour period, somewhat later in the afternoon than three years previously, and again the low ratios coincided with major cleaning activity.

Literature data for BOD_5/COD ratios in a soap manufacturing plant (312) reveal low values associated with surfactants and boiler treatment (Table 26).

Information obtained from plant surveys (see Appendix 1 for form used in site visits and personally handed to plant management for their assistance) provide limited data for different types of dairy food plants concerning COD_5/BOD ratios of raw and treated wastes. The data is tabulated in Table 27.

Raw waste water coefficients ranged from 0.40 to 0.97, with most ratios below 0.5. The ratios became lower in the treated wastes, as would be expected. However, four of the seven ratios were below the 0.25 ratio reported for treated industrial waste (315). Because of the high initial BOD values in many of the plants, the COD in the treated wastes were high for the seven plants, ranging from 100 to 700 ppm. This suggests a significant concentration of refractory-organic materials in dairy plant wastes, which probably come from detergents and sanitizers.

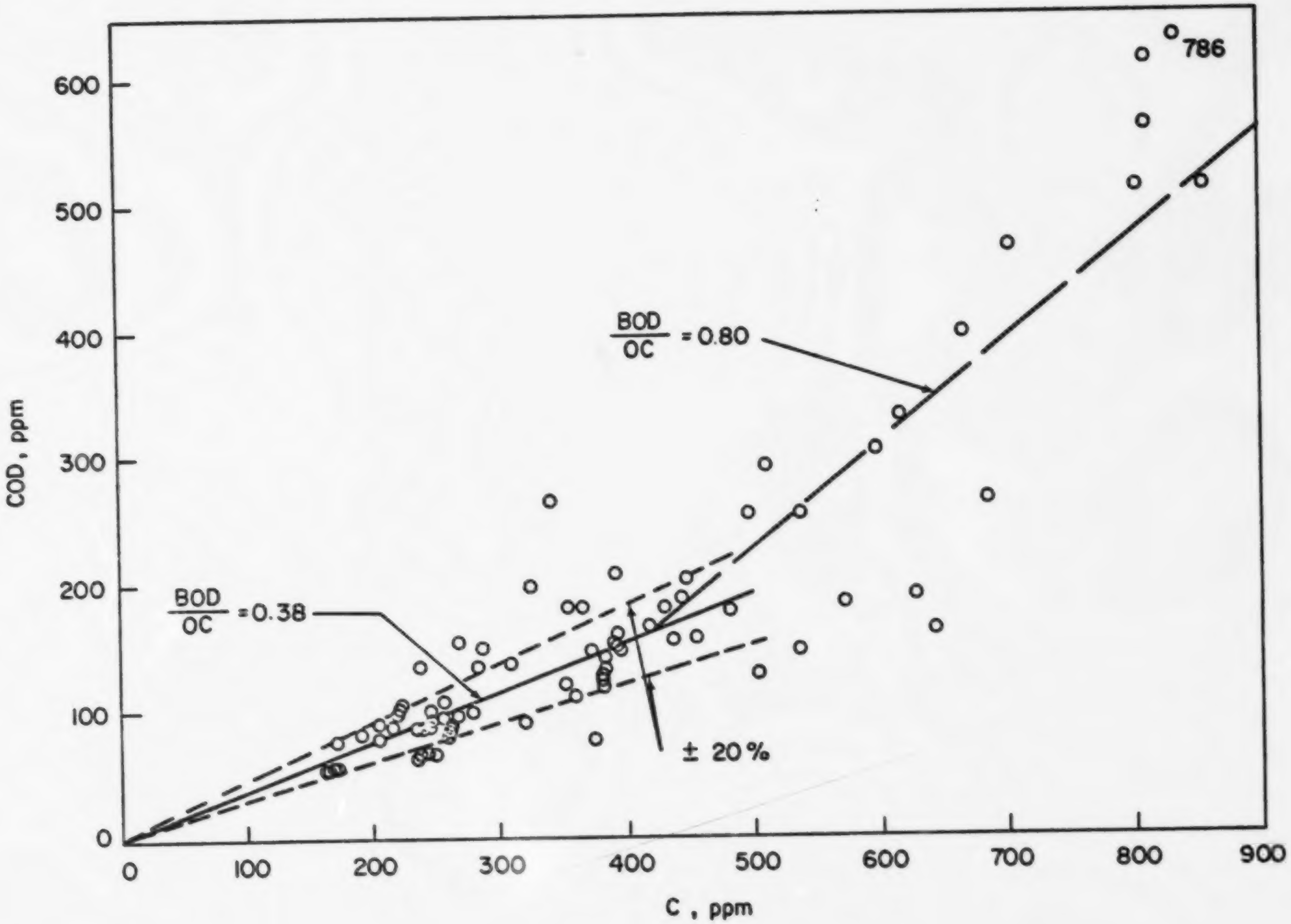


Figure 4 - Comparison of BOD with O.C. (COD) of dairy wastes (after Hoover, 466)

Table 24 - BOC/COD Relationships in Raw and Treated Dairy Plant Wastes (1967) at Hourly Intervals*, **

Time	BOD:COD Ratios		Rate of Waste Water Flow (mgd)	Raw COD Values
	Raw	Treated		
8:00 a.m.	.4	.32	.025	3440
9:00 a.m.	.35	.29	.020	3200
10:00 a.m.	.51	.26	.025	3400
11:00 a.m.	.28	.25	.010	4700
12:00	.66	.15	.035	2600
1:00 p.m.	.26	.48	.035	3400
2:00 p.m.	.21	.90	.035	5200
3:00 p.m.	.21	.82	.050	5800
4:00 p.m.	.12	.77	.035	9280
5:00 p.m.	.25	.59	.045	6240
6:00 p.m.	.45	.75	.035	7760
7:00 p.m.	.60	.57	.014	3200
8:00 p.m.	.57	.68	.020	4480
9:00 p.m.	.55	.54	.020	2720
10:00 p.m.	.88	.64	.022	2400
11:00 p.m.	.90	.63	.010	1056
12:00	.90	.60	.005	886

*Equipment sanitized 6:00 - 8:00 a.m.

**Clean up 1:00 - 6:00 p.m., maximum activity about 2:00 - 4:00 p.m.

Table 25 - BOD_5:COD Relationships in Dairy Plant Raw Waste Water at Hourly Intervals During a One-day Period*

	BOD	COD	BOD/COD Ratio	Flow Rate, mgal/24 hr
12:00 Midnight	1680	2680	.62	27
1:00 a.m.	1425	2280	.54	24
2:00 a.m.	1335	2481	.53	23
3:00 a.m.	1365	2440	.56	24
4:00 a.m.	3660	6650	.55	21
5:00 a.m.	2220	5060	.43	19
6:00 a.m.	1560	2930	.59	24
7:00 a.m.	1095	1740	.63	22
8:00 a.m.	960	1640	.58	21
9:00 a.m.	1440	2830	.51	25
10:00 a.m.	2340	3620	.64	23
11:00 a.m.	1485	2430	.61	22
12:00 Noon	2160	3210	.67	22
1:00 p.m.	4020	6850	.59	22
2:00 p.m.	2640	4330	.61	24
3:00 p.m.	3060	4470	.60	25
4:00 p.m.	3060	4330	.60	29
5:00 p.m.	3120	4730	.65	27
6:00 p.m.	3540	17344	.20	26
7:00 p.m.	3540	17160	.21	25
8:00 p.m.	2700	18480	.14	25
9:00 p.m.	2400	5170	.36	27
10:00 p.m.	2340	4980	.47	26
11:00 p.m.	2100	4370	.48	26
Average	2302	5508	.42	24.1
24-Hr. Treated	230	650	.35	24.1

*Major clean-up 5:00 - 8:30 p.m.

Table 26 - COD:BOD Ratios for the Waste from a Soap Manufacturing Plant (Eckenfelder-Industrial Water Pollution Control, 1966)

Process Area	BOD/COD Ratios
Liquid Soap	.51
Toilet Articles	.57
Soap Products	.55
ABS Production	.26
Powerhouse	.15
Spent Caustic	.33
Tank Bottoms	.80
Main Sewer	.54

Table 27 - BOD_5/COD Relationships in Raw and Treated Dairy Plant Wastes from Survey of Industrial Dairy Plants

Plant No.	Products Manufactured	Type of Waste Treatment*	Raw Dairy Plant Wastes			After Primary Treatment			After Secondary Treatment		
			BOD_5	COD	BOD/COD	BOD_5	COD	BOD/COD	BOD_5	COD	BOD/COD
10	Milk Cottage Cheese	None	3300	3379	.97	--	--	--	--	--	--
11	Milk Cottage Cheese	AS,AL	3700	7071	.52	145	400	.36	15	100	.15
12	Milk Yogurt Cottage Cheese	AS	750	850	.88	400	600	.67	80	250	.32
13	Cottage Cheese Milk	TF	2863	6500	.44	--	--	--	266	700	.38
46	Milk Cottage Cheese Ice Cream	TF	3200	9000	.41	145	430	.33	15	175	.08
	Milk Ice Cream Butter Cottage Cheese	AS	2168	5300	.40	140	350	.40	35	250	.14
30	Milk Ice Cream Cottage Cheese	AS	3750	9000	.41	--	--	--	150	560	.26
31	Milk Ice Cream Cottage Cheese	None	3200	4150	.51	--	--	--	--	--	--
24	Ice Cream	AS	140	350	.40	--	--	--	35	250	.14

*AS = Activated Sludge, AL = Aerated Lagoon, TF = Trickling Filter

Other Characteristics of Dairy Food Plant Wastes

In addition to volume and BOD, other characteristics of dairy plant wastes that have significance or potential significance to waste treatment practices include: (a) suspended solids, (b) total solids, (c) volatile (organic) solids, (d) pH, (e) temperature, (f) inorganic constituents of dairy products, (g) detergent chemicals, (h) sanitizing chemicals and (i) chemicals used as lubricants. The information concerning these characteristics is less available both in the literature and in industry than information concerning volume and BOD characteristics. In some areas, such as food plant detergents and lubricants, there is little or no information available in the literature.

SOLIDS

In respect to treatment of waste waters, solids content and pH are considered to be next in importance to BOD and volume and information for these two characteristics is generally reported together, and will be so considered in this report.

The solids of waste waters are generally separated into three or four categories:

1. Settable solids - reported in ml/1 based on gravity settling.
2. Suspended solids - reported in ppm; all material removed by filtration included.
3. Volatile solids - reported in ppm; represents the solids lost by ashing, generally considered to reflect organic solids.
4. Total solids - reported in ppm; obtained by drying to constant weight.

Literature Values: Available information for solids and pH content of dairy plant waste waters in relation to plant type and BOD strength in ppm is presented in Table 28. The suspended solids content of dairy plant waste varied widely, ranging from 6 to 4500 ppm and is generally lower than the BOD; although one value is reported for wastes from a butter plant in which the suspended solids was higher in concentration than the BOD_5 value. Based on the limited literature available, there was no statistically significant correlation between the suspended solids strength and the type of dairy plant operation. Based on the limited available data on both suspended solids and volatile suspended solids, it would appear that over 70% of the suspended solids is volatile or organic in nature in dairy food plant waste waters. Volatile suspended

Table 28 - Literature Values for BOD - Solids Relationships and pH of Industrial Dairy Plant Wastes

Author	Product	ppm of Following					pH
		BOD ppm	Sus. Solids	Vol. Sus. Solids	Vol. T. Solids	Total Solids	
Gauchmen (1940)	Cheese	13760	4500	-	-	-	8.0
Hatch (1940)	Cheese	775	-	-	-	1246	6.7
McKee (1957)	Cheese	1890	396	560	2698	4516	5.7
Schweizer	Cheese	1000-2700	-	-	-	1500-8500	7.1-7.4
Sarka, et al. (1970)	Cheese	1045	306	-	1391	2192	8.4
Gauchmen (1940)	Butter	3760	-	-	-	5300	7.6
Hatch (1940)	Butter	1246	-	-	-	2242	7.7
Morgan (1957)	Butter	3030	-	1360	1740	-	-
Schweiger (1968)	Butter	250-1700	-	-	-	700-4000	7.6-8.3
Sarka, et al. (1970)	Butter	873	354	-	763	1158	8.1
Hatch (1940)	Conden. Milk	1291	-	-	-	2793	7.8
Morgan (1957)	Powder	2150	-	500	1199	-	-
DeMartini (1946)	Whey Drying	15	24	17	57	156	7.7
		574	67	44	166	450	-
		623	6	-	102	135	7.2
Montagne (1940)	Milk	545	-	-	-	797	7.3-8.1

Table 28 - continued

Author	Product	ppm of Following					pH
		BOD	Sus. Solids	Vol. Sus. Solids	Vol. T. Solids	Total Solids	
HasFurther (1949)	Milk	1010	250	230	1320	1340	7.9
Silvester (1959)	Milk	1000	819	-	-	-	-
Grewis (1966)	Milk	634	74	-	-	-	-
Sarka, et al. (1970)	Milk	713	271	-	720	1069	8.5
Anderson (1968)	Butter, Powder	3060	1322	-	-	3182	4.4
Bergman (1966)	Cheese, Butter	549	-	-	1548	-	-
Walgren (1966)	Cheese, Butter	780	-	-	1130	2300	5.3-9.2
Bloodgood (1947)	Dairy Products	548	-	-	-	863	8.0
Lawton, et al. (1959)	Unknown Dairy Products	4790 4310 1280 1241	1025 1040 361 619	998 910 303 561	3800 4740 1350 1240	5450 6490 2280 2653	5.6 4.8 6.8 6.4
Silvester (1959)	Unknown Dairy Products	860 1130	539 819	- -	- -	- -	5.0 5.0

solids as percent of total suspended solids ranged from 69 to 98% and averaged 85%. The suspended solids would be composed primarily of coagulated milk, fine particles of cheese curd and pieces of fruits and nuts from ice cream operations. Suspended solids comprised from 10 to 30% of the total solids. The relationship of volatile to total solids ranged from 36 to 96% with an average of 64%. The 37% of nonorganic total solids is about twice the 15% nonorganic volatile suspended solids. The proportion of nonorganic solids in milk is about 13%, which suggest that most of the suspended solids are of a dairy or food product origin. The increased nonorganic matter in the total solids would reflect the contribution of nonorganic material in both detergents and sanitizers.

The pH of dairy plant wastes varied from 4.4 to 9.2, with a median value of 7.2. No apparent relationship existed between the type of diary plant operation and the pH of the wastes. It would be expected that cheese operations might have a lower pH than other types of plants because of the low pH of whey, but this is not reflected in the data. The major factor affecting pH of dairy plant wastes is the cleaning compound and its relative significance in the dairy plant wastes. This will be discussed in detail later in the report.

The relationships of BOD to various total solids content of dairy food plant wastes is summarized in Table 29. Suspended solids/BOD ratios ranged from 0.28 to 0.35 and averaged 0.31, whereas the total solids/BOD ratios were essentially identical for different types of dairy plants with an average value of 1.62. The relationships of solids to BOD appears to be independent of the type of dairy plant operation and a characteristic of all dairy plant waste waters.

Table 29 - BOD-Solids Relationships in Dairy Food Plant Waste Waters

Product	Sus. Solids/BOD Ratio	Total Solids/BOD Ratio	Sus. Solids/Total Ratio
Cheese	0.35	1.6	0.33
Butter	0.28	1.65	0.30
Milk	0.32	1.7	0.75
Combined Dairy Products	0.35	1.6	0.52
Average	0.32	1.62	0.47

Industrial Data: Solids and pH values were available for 10 of the 56 dairy plants surveyed in this investigation. The values in relation to BOD and plant type are summarized in Table 30. The values reported were within the range of literature values for both total and suspended solids. The suspended solids, however, were generally higher than most literature reports. For 4 of the 10 plants, the suspended solids values were higher than the BOD values. The ratio of suspended solids/BOD ranged from 0.07 to 1.4 with an average of 0.78. The data for ice cream operations are the first available, and suggest that this type of dairy plant operation generates more suspended solids in relation to BOD than other types of dairy food plant operations. However, the data must be interpreted with caution, since only limited data are available.

Table 30 - BOD — Solids Relationship from Industrial Dairy Food Plant Wastes

Plant No.	Product	BOD	Suspended Solids		Total Solids	pH
			Volatile	Total		
23	Ice Cream	3700	5260	-	6562	7.2
24	Ice Cream	450	400	600	1000	7.0
37	Cottage Cheese	5700	80	384	436	9.4
10	Milk and Cottage Cheese	3300	2129	2951	3480	4.6
11	Milk and Cottage Cheese	3700	5260	-	6562	7.2
12	Milk and Cottage Cheese	750	250	850	1250	7.6
7	Milk, Cottage Cheese, Milk Powder	1700	-	250	3000	7.3
30	Milk, Ice Cream, Cottage Cheese	2160	-	2350	3200	7.6
33	Milk, Ice Cream, Cottage Cheese	4000	-	860	-	8.0
34	Milk, Ice Cream, Cottage Cheese	3200	-	1500	-	6.8

Temperature: Only limited studies have been made of the temperature of dairy plant waste waters as they leave the dairy plant. Reported values range from 70°F to 110°F (20°C-40°C). Literature values are summarized in Table 31. Zall (1289) showed that waste water temperatures in a small dairy plant could be reduced about 15°F by management control of the use of hot water in cleaning and by eliminating the practice of allowing hot water hoses to run while not in actual use. The data for waste water temperature was available for 10 plants in this study and values ranged from 70 to 102 (presented in a frequency plot in Fig. 5). The figures fall in a fairly normal distribution which suggest an average temperature of 85°F and a maximum temperature (1% confidence limit) of 110°F. Temperatures of cleaning solutions, proportion of cleaning solutions as percentage of total waste water, and degree of hot water conservation, will be the primary factors controlling the temperature of dairy food plant waste waters. Condensing operations will result in elevation of waste water temperatures to over 100°F.

Table 31 - Temperature of Dairy Food Plant Waste Water

Investigator	Temperature	
	Range	Average
Backmeyer (1949)	--	100°F
Gloyna (1950)	70 - 90	80
McKee (1958)	--	98°F
Bergman (1961)	65 - 113°C	
Jeris (1966)	70 - 90°	90 ± 0.1°C
Zall (1968) No control of water usage	100 - 105°F	
Control of water usage	84 - 91°F	
Fraser (1968)	85 - 103°F	--

Chemical Composition of Dairy Food Plant Waste Waters

No systematic complete study of the chemical composition of dairy plant wastes has been made to date, and only limited data is available. The most comprehensive studies have been those of Walgren in 1966 (1201) and Sarka in 1970 (920) for dairy plants in Sweden and Finland, respectively. However, these studies are not complete; Sarka omitted fat analyses from his study and Walgren omitted protein and carbohydrate data.

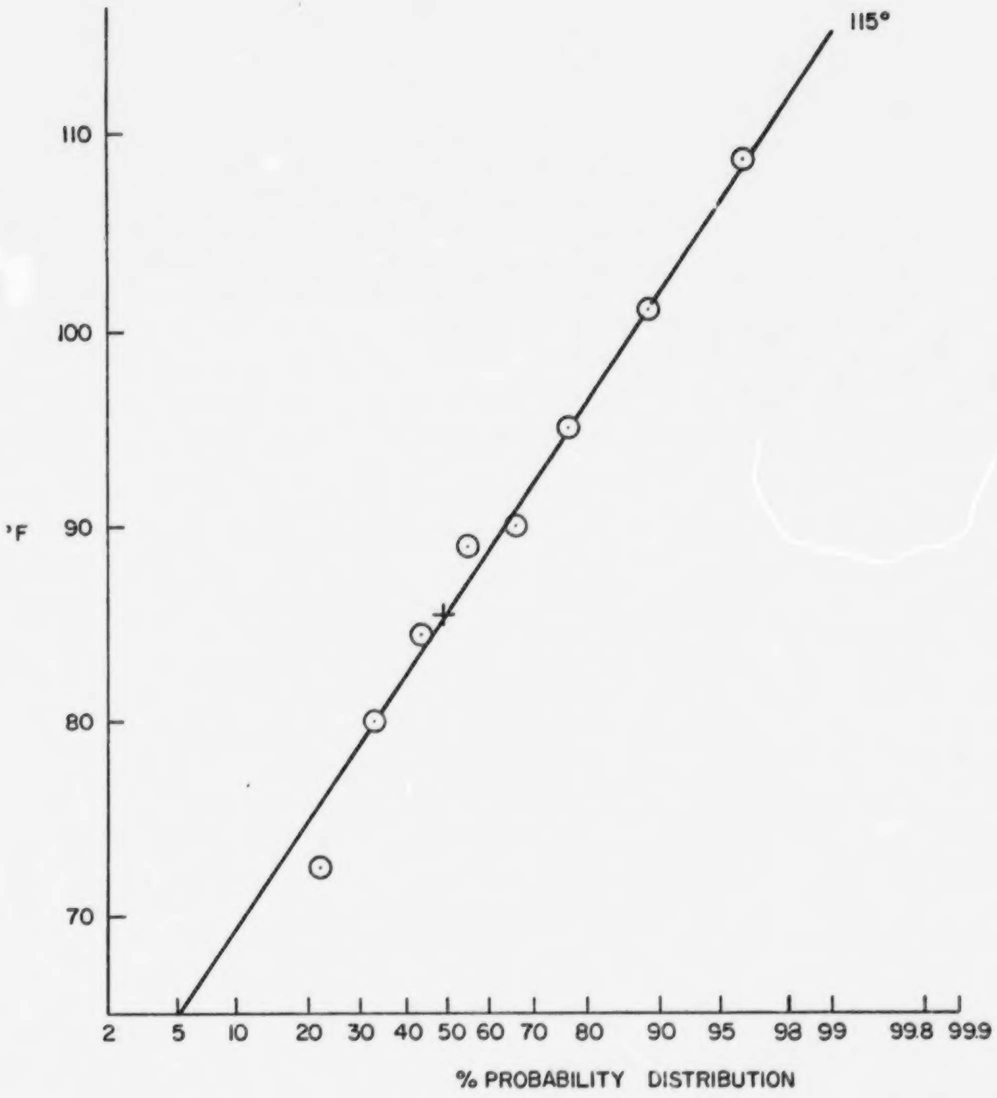


Figure 5 - Percentage distribution of waste water temperature for 10 commercial dairy food plants

Compositional data for the major inorganic constituents in dairy food plants wastes are essential to a better understanding of the consistency of composition of dairy wastes and the oxygen requirements of these waste waters, since the oxygen consumed varies widely from compound to compound. Information on the mineral constituents of dairy plants wastes is important because of the roll of various refractory elements in water quality. The refractory inorganic elements, concentrations considered to impair water quality and the effect of these elements on water quality is summarized in Table 32. All of the elements listed are found in dairy wastes, either as milk constituents or as components of cleaning compounds and detergents. Table 33 shows the effect of various treatments on the removal of the various inorganic elements, indicating little removal by secondary sewage plant treatment or by natural purification. Therefore, control of the concentration of these elements requires either the utilization of water purification treatments or their exclusion from the waste waters.

The organic composition and the concentration of phosporous and chloride reported in the same studies providing information on organic content are presented in Table 34 for both literature and industrial survey data available for the 56 plants providing waste water information. The limited data indicated differences in the ratios of protein and fat to lactose. Ratios for whole milk and for the data available follows.

Source	Protein/lactose ratio	Fat/lactose ratio
Whole milk	0.64	0.70
Dairy waste water	0.56	0.12
Dairy waste water	0.43	--
Dairy waste water	0.85	0.57
Dairy waste water	1.08	--
Dairy waste water	1.14	--
Dairy waste water	0.32	0.05

The protein/lactose ratios in dairy food plant wastes were both higher and lower than the whole milk ratios, and none of the ratios in dairy wastes for protein and lactose were those expected from the milk values. The fat/lactose ratios were lower than for whole milk and the three available figures varied markedly from each other. Since the data come from different types of plants in different countries, much

Table 32 - Concentrations of Inorganic Refractory Ions Causing Damage

	Concentration Causing Effect, Parts/Million	Effect
Cations		
Calcium	Over 100 (as $CaCo_3$ undesirable for municipal use)	Adds hardness
Magnesium	Same as calcium as $MgSO_4$	Same as calcium
	1,000-2,000	Cathartic
Sodium	200	Physiological effect on persons with cardiac, renal or circulatory disease
	50	Foaming in boilers
Potassium	1,000-2,000	Cathartic
	56	Foaming in boilers
Ammonia	Any amount	Requires excess chlorine at water plant
	2.5	Toxic to fish
Anions		
Bicarbonate	Any amount	Source of nitrates
	Over 200 undesirable	Contributes to salinity and solids
	Over 100 undesirable	Hardness if as $Ca(HCO_3)_2$
Chloride	250	Salty taste
	75-200	Interferes with industrial processes
Sulfate	600-1,000	Cathartic
Nitrate	0.3	Nutrient stimulating undesirable aquatic growth
	15-200	Methemoglobinemia in infants
Phosphate	0.015	Nutrient stimulating undesirable aquatic growth

Table 33 - Effectiveness of Sewage Treatment, Natural Purification, and Water Treatment on Removal of Common Inorganic Ions

Common Inorganic Refractory Ions	Effectiveness of Removal		
	Secondary Sewage Treatment	Natural Purification	Water Treatment
Catons			
Calcium	Little or none	Little or none	Yes - if water is softened
Magnesium	Little or none	Little or none	Yes - if water is softened
Sodium	None	None	None
Potassium	None	None	None
Ammonia	Builds up during nitrogen decomposition. Partial removal by oxidation to nitrates	Slowly changes to nitrate	May be oxidized by chlorine or caused to form chloramine
Anions			
Bicarbonate	Little or none builds up in digester	Little or none	Yes - if present in Ca or Mg form and softened
Chloride	None	None	None
Sulfate	Little or none	Little or none	None
Nitrate	Treatment usually increases nitrates	Used by plant life in growth	None
Phosphate	Partial (80-90%)	Partial removal by utilization by plants	Little or none

Table 34 - Chemical Constituents of Industrial Dairy Plant Wastes

Author	Product	ppm							
		BOD_5	N	Organic C	Protein	Sugar	Fat	P.	Cl
McKee (1957)	Cheese	1890	73	-	-	-	-	59	-
Schweizer (1968)	Cheese	-	-	-	560	700	90	--	-
Sarka, et al. (1970)	Cheese	1045	52	723	423	931	-	15	-
Schweizer (1968)	Butter	-	-	-	300	350	200	-	-
Sarka, et al. (1970)	Butter	873	51	512	324	300	-	13	-
Sarka, et al. (1970)	Milk	713	52	434	288	252	-	12	-
Walgren (1966)	Cheese, Butter	780	87	-	-	-	217	15	48
Lawton, et al. (1959)	Unknown Dairy Products	1752	-	-	-	-	-	17	180
Lawton, et al. (1959)		4790	170	-	-	-	-	132	264
Lawton, et al. (1959)		4310	180	-	-	-	-	60	494
Lawton, et al. (1959)		1280	58	-	-	-	-	35	162
Lawton, et al. (1959)		936	43	-	-	-	-	31	559
Svoboda, et al. (1962)	Cheese	1550	92	-	210	650	35	-	-
Plant No.									
23	Ice Cream	3700	15	-	-	-	-	205	470
24	Ice Cream	450	24	-	-	-	100	40	200
10	Milk and Cottage Cheese	3300	109	-	-	-	325	21	110
12	Milk and Cottage Cheese	750	-	-	-	-	500	40	-

Reproduced from best available copy.

more data is needed to ascertain if the type of dairy plant operation, cleaning procedures and/or processing variables relate to the relative amounts of protein, fat and lactose in dairy food plant waste waters. Such data would be useful in interpreting differences in treatment efficiencies with the same treatment system operating for different dairies at the same loading.

The phosphate values varied independently of BOD, were all in excess of 10 ppm, and would be considered as a potential source of phosphate for enhancing algae growth. The values varied widely, apparently reflecting the different amounts of phosphate cleaning compound used in the dairy operation. European values are generally lower than those reported for American dairy plant operations and this can be explained because European dairy plants use less phosphate in their detergents, frequently using none at all. Most chloride values in the waste water exceed the 75 ppm considered to interfere with industrial processes and four of the nine values given exceed the 250 ppm that can give a salty taste to the water and interfere with the use of the water as a source for reconstituting dried food products. One waste water value for chloride exceeded the 500 ppm limit suggested as the highest level for use in drinking water.

To interpret the data for these and other refractory elements in dairy wastes, values for calcium, sodium, potassium, phosphorous, magnesium, chloride and nitrogen are given for milk and milk products in Table 35. Converting the values to elemental composition, milk waste containing 1% (10,000 ppm) milk would contain:

BOD	1000 ppm
Nitrogen	55 ppm
Chloride	10 ppm
Phosphorous	12 ppm
Calcium	12 ppm
Sodium	4 ppm
Potassium	15 ppm
Magnesium	5 ppm

Assuming all of the BOD in dairy wastes to be of milk origin, the contribution of milk to various mineral constituents are shown as a function of BOD in Figure 6. Much more chemical composition data of dairy plant wastes is needed to determine the value of using BOD component relationship in Figure 6 as a basis of assessing the contribution of milk solids to dairy plant wastes and evaluating non-milk component contributions from BOD values. BOD-milk component relationships plus material balances for cleaning compounds, sanitizers and lubricants, may provide the basis for developing a formula to calculate the most probable chemical composition of dairy food plant wastes with minimal analysis.

However, based on available information, it would appear that the phosphorous content of the dairy wastes from the European studies (920, 988, 1201) can be accounted for entirely on the basis of milk

Table 35 - Content of Mineral Matter and Nitrogen in Milk and Its Products and By-Products

Dairy Product	ppm of Fluid Product						
	Calcium as CaO	Sodium as Na_2O	Potassium as K_2O	Phosphorous as P_3O_5	Magnesium as MgO	Chlorine as Cl	Nitrogen as N
Whole Milk	1510	620	2010	2010	200	1050	5500
Cream	90	0370	1210	1210	120	630	3300
Butter, salted	--	660	--	--	--	9400	--
Butter, unsalted	--	--	--	--	--	--	--
Skim Milk	1590	650	2110	2110	200	1100	5700
Buttermilk	1570	640	2090	2090	200	1090	5600
Cheese Whey (sweet)	50	660	2020	1010	100	1140	1360
Rennet Casein Whey	460	60	2000	900	100	1140	1360
Lactic Casein Whey	150	6000	2000	2000	200	1000	1300

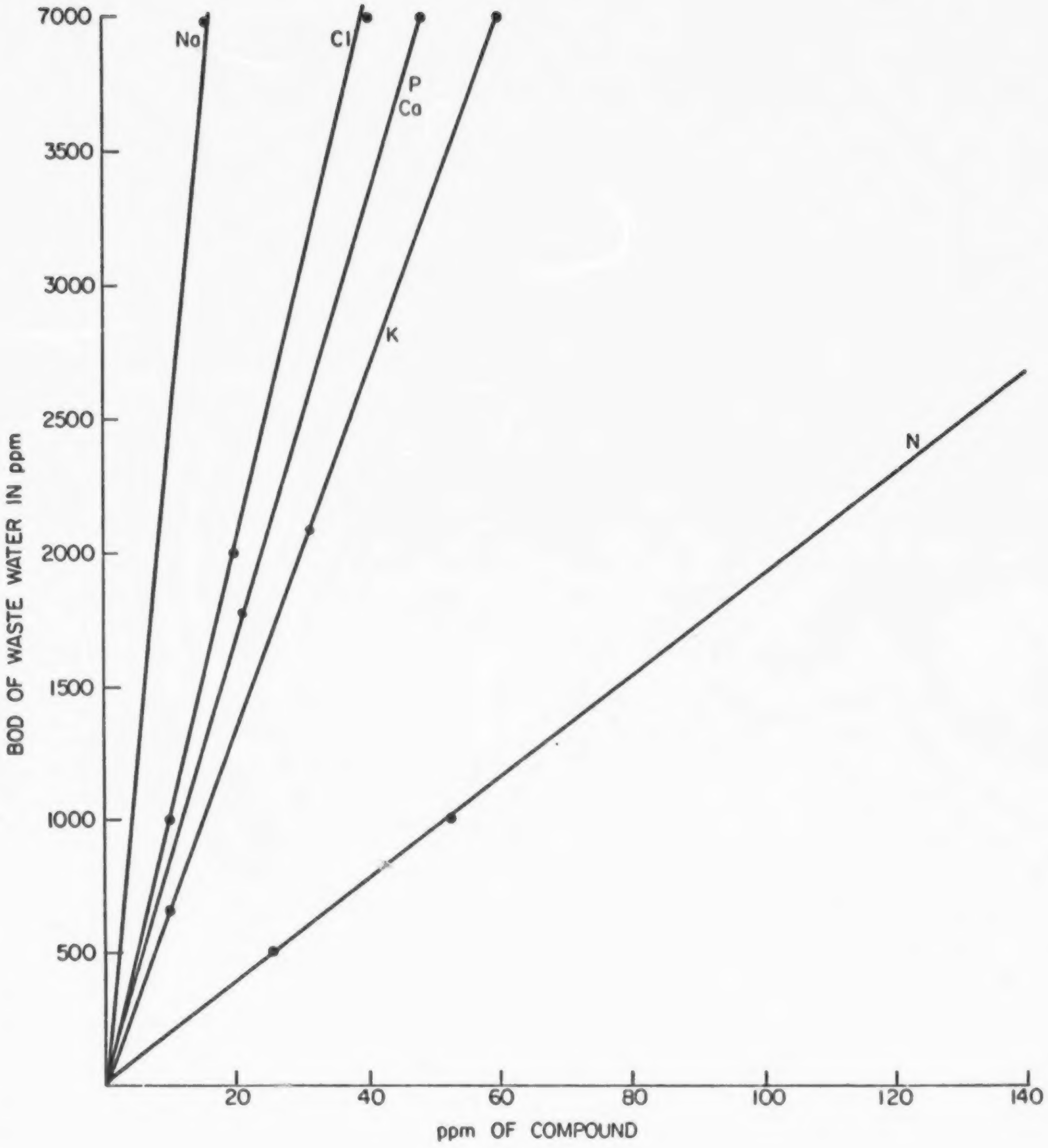


Figure 6 - Relation of mineral components to BOD of milk wastes

phosphorous content, whereas milk phosphorous contributes from about 10 to 30% of the phosphorous in the waste water of American dairy food plant waste waters.

Available data for Mg, Ca, Na, and K are summarized in Table 36 together with BOD_5 values. No values were reported for these constituents by any of the industrial plants in the survey made during this investigation. The values differ widely in respect to sodium (60-807 ppm) and potassium (11-160 ppm) and were less variable for magnesium (25-49 ppm) and calcium (66-112 ppm). Variation in the latter two minerals reflected variation in BOD, whereas a variance in sodium and potassium were not related necessarily to BOD and probably reflect differences in sodium and potassium in cleaning compounds and water treatment (ion exchange) in the different plants.

Table 36 - Mineral Composition of Dairy Food Plant Waste Water

Investigator	ppm of Following				
	BOD_5	Mg	Ca	Na	K
McKee (1955)	1080	25	112	807	116
Lawton (1959)	1752	49	76	166	60
Lawton (1959)	4790	40	76	374	138
Lawton (1959)	4310	35	78	433	160
Lawton (1959)	1280	37	57	255	47
Lawton (1959)	936	37	66	470	37
Walgren (1968)					
First yr.	1560	--	109	60	11
Second yr.	780	--	111	328	22
Third yr.	970	--	100	101	12.5
Average		37	87	322	67

Based on the data in Figure 6, milk salts could contribute about 10-50%, 10-75%, 1-10% and 25-100% of the magnesium, calcium, sodium and potassium ions in the dairy plant waste waters. Thus, about 90% of the sodium, 50% of the magnesium, and 25% of the calcium appear to come from nondairy sources; presumably the cleaning compounds, detergents and lubricants.

Lubricants: Lubricants are not mentioned in the literature as a source of pollutants in dairy plant waste waters, and only limited information could be obtained during the course of the study concerning the specific contribution of these materials to BOD. This will be covered under the section on sources of dairy wastes since they are a visible source of BOD.

Chemically, most lubricants used in the dairy industry fall into the category of soaps or silicones. Lubricants used for case stackers and conveyors of all types are generally soaps. These are either potassium or sodium salts of saponified fats. The characteristics of the lubricant are determined to a large extent by the chain length of the fatty acids. Some manufactures prefer lubricants derived from coconut or palm kernel oil, which are high in lauric acid. Based on previously reported data (Table 8), the chain length of the acid has a material effect on the BOD_5 value. Some manufacturers use fatty amides, which have a low BOD_5 value and could contribute to the apparent toxicity of some dairy food plant waste waters. The pound BOD/pound product ranges from 0.22 to 0.45 for fatty amides from different sources. Silicones are refractory compounds, but are not widely used because they are not as satisfactory as soaps.

Detergents and Sanitizers

Detergents: As reported previously in Waste Profile No. 9 (355), detergents make up a small amount of the BOD load of dairy plant wastes, but as indicated earlier in this report, they are potentially significant as a source of toxic materials and are significant as sources of refractory inorganic elements in dairy food plant wastes.

Generally, cleaning compounds are classified into two main groups, the alkaline cleaners and the acid cleaners. The alkaline cleaners are generally comprised of basic alkali, polyphosphates and wetting agents. None of the basic alkalis, higher phosphates or wetting agents can meet all the requirements of a good cleaner when used alone. Blends of mixtures of these chemicals can be made, however, which bring several of these properties together in one product.

The basic alkalis, such as soda ash, caustic soda, trisodium phosphate and sodium metasilicate, form the bulk of most of the common dairy cleaners. Two or more of them are used in combination as a rule to give certain properties to the blended product. In addition to providing alkalinity for the cleaning process, they have other properties which affect the cleaning process in various degrees. Caustic soda ($NaOH$) is used in many CIP cleaning systems. Soda ash, which was once the principal component of washing powders, is gradually being replaced by other alkalis.

Trisodium phosphate has become a very popular constituent in dairy cleaners because of its ready solubility and high deflocculating and emulsifying powers. It is a fair water softener because of the flocculent character and insolubility of the calcium and magnesium phosphates formed. When compared with metasilicate or soda ash, trisodium phosphate is also relatively corrosive on tin unless metasilicate is present as a protective agent in the mixture.

Sodium metasilicate has high active alkalinity and excellent deflocculating and emulsifying properties. It, like trisodium phosphate, is only a fair water softener. The calcium and magnesium silicates formed in hard water are flocculent and insoluble in solutions. Although it is the strongest alkali next to caustic, it is relatively noncorrosive and has the property of protecting metals against corrosion by other alkalis. Metasilicate is very effective in holding the soil in suspension during the washing operation so that complete cleaning is possible.

The contribution of various compounds to alkalinity and pH is listed in Table 37.

Table 37 - Properties of Common Cleaner Components

Cleaner	pH		Total Alkalinity	Active Alkalinity
	0.1%	1.0%		
Caustic soda (NaOH)	12.3	13.1	76.5	76
Soda ash	10.9	11.3	58.1	29
Baking soda	8.4	8.2	37.4	0
Metso (Na silicate) H_2O anhydrous	11.5	12.4	29.3	28
TSP Trisodium phosphate	11.3	12.0	24.5	11
Tetrasodium phosphate	10.1	10.2	46.6	8
Quadrafos (Sodium tetraphosphate)	7.6	8.0	39.6	0
Calgon (Sodium hexametaphosphate)	6.1	5.4	30.4	0

The complex phosphates are excellent cleaning compounds and are considered first in respect to water softening. In addition to their water condition in properties, the complex phosphates are valuable in respect to emulsification, dispersion, protein peptizing and prevention of soil redisposition. However, the pyrophosphates have the lowest effectiveness in respect to these properties and is the most widely used.

It lacks calcium sequestering power as compared with the higher phosphates, but has the advantage of being more stable under high temperature and high alkalinity conditions. Tripolyphosphate and tetraphosphate are definitely superior to pyrophosphate in sequestering power on calcium hardness which is the form present to the greatest extent in natural waters. Sodium tetraphosphate, also known as Quadrafos, ranks just above trapolyphosphate in this respect and is somewhat higher in price. Hexamethaphosphate, also known as Calgon, is the most effective sequestering agent when calcium hardness alone is considered. It is the most expensive member of the group. In comparison with the other phosphates it lacks sequestering power on calcium in the presence of magnesium hardness and this may be a limiting factor in some areas. Hexamethaphosphate is unstable under high temperatures and alkaline conditions.

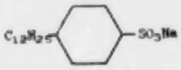
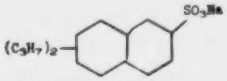
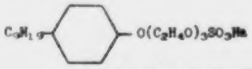
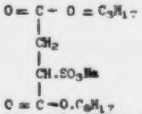
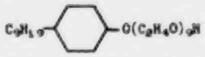
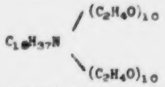
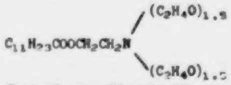
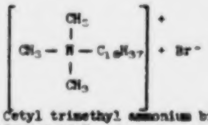
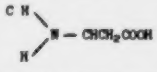
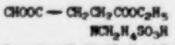
Wetting agents are widely used today in all phases of dairy cleaning, but in most instances they are used in relatively low percentages. Wetting agents are soluble in cold water and in the usual concentrations are not affected by water hardness. This permits better rinsing in hard water with the result that equipment is cleaner and brighter in appearance. Wetting agents are effective over a wide range of acid and alkaline conditions which permits their use in acid type cleaners as well as in alkaline washing powders. When added to these cleaners, the wetting agents improve the wetting or penetrating power of the product. Even in low concentrations, such as 0.15 per cent of the total detergent, they reduce the surface tension of water to half of its original value. It is important to note that increased concentrations fail to give any material lowering of surface tension, and therefore, the amounts used in cleaners are usually small. Wetting agents also contribute some emulsifying and deflocculating properties to cleaning solutions, but these properties can be provided more economically by the use of metasilicate compounds. They are the major components to contribute BOD and may also decrease oxygen transfer in waste treatment plants (314).

There are three general types of these materials (see Table 38):

1. The anionic wetting agents. These are the most common of the wetting agents. They are essentially neutral materials, but usually can be adjusted for use in either an acid or alkaline medium. Chemically, the sulfated alcohols and alkyl aryl sulfonates are the most common. There are thousands of possible combinations of this nature, some few hundred of which are available. Many of them have highly specialized uses and may not be suitable for cleaning.

2. The nonionic wetting agents. They are essentially complex organic chemicals which are relatively new on the market. They have been finding increasing uses. Many of these are liquids and contain no water. As they do not ionize, they may be used with either anionic or

Table 38 - Chemical Nature of Wetting Agents in Detergents

Class	Type	Example
Anionic	Soap	$C_{15}H_{30}COONa$ Sodium palmitate
	Alkyl sulphate	$C_{12}H_{25}OSO_3Na$ Dodecyl sulphate
	Alkyl aryl sulphonate	 Dodecyl benzene sulphonate
	Naphthalene sulphonate	 Di-isopropyl naphthalene sulphonate.
	Polyether sulphate	 Sulphate of nonyl phenol 5 mole ethoxylate
	Sulphosuccinate	 $O=C-O=C_8H_{17}$ CH_2 $CH.SO_3Na$ $O=C-O.C_8H_{17}$ Di-octyl sulphosuccinate
Nonionic	Ethoxylated phenol	 Nonyl phenol condensed with 9 moles of ethylene oxide. 'Teric' N9, 'Teric' GN9.
	Ethoxylated alcohol	$C_{12}H_{25}O(C_2H_4O)_9H$ Lauryl alcohol condensed with 9 moles of ethylene oxide. 'Teric' 12A9.
	Ethoxylated amine	 $C_{18}H_{37}N\begin{matrix}(C_2H_4O)_{10}\\(C_2H_4O)_{10}\end{matrix}$ Stearyl amine condensed with 20 moles of ethylene oxide. 'Teric' 18M20.
	Ethoxylated amide	 $C_{11}H_{23}COOCH_2CH_2N\begin{matrix}(C_2H_4O)_{1.5}\\(C_2H_4O)_{1.5}\end{matrix}$ Coconut monoethanolamide condensed with 3 moles of ethylene oxide. 'Teric' CME3.
	Ester	$C_3H_7O_3.CO.C_{11}H_{23}$ Glyceryl monolaurate
Cationic	Quaternary ammonium	 $\left[\begin{matrix} & CH_3 & \\ CH_3- & N & -C_{16}H_{37} \\ & CH_3 & \end{matrix}\right]^+ + Br^-$ Cetyl trimethyl ammonium bromide "Cetrimide".
	Amine	$C_{18}H_{37}NH_2$ Stearyl amine
Amphoteric	Amino acid derivative	 $\begin{matrix}C\ H\\H\end{matrix}N-CHCH_2COOH$ Lauryl β-amino propionic acid.
	Laurine derivative	 $CHOOC-CH_2CH_2COOC_2H_5$ $NCH_2H_4SO_3H$ Laurine N-diethyl maleate

cationic materials. They are also compatible with most other cleaning chemicals, and generally are poorly degraded in biological systems.

3. The cationic wetting agents. The best known examples of this group are the quaternary ammonium compounds. The two most extensively used are: Di-isobutyl phenoxy ethoxy ethyl dimethyl benzyl ammonium chloride and alkyl (C_8H_{17}-$C_{18}H_{37}$) dimethyl benzyl ammonium chloride. These products are finding increasing use as germicides rather than as cleaners. Although they belong to the wetting agent family, in comparison with the other groups, they are rather poor wetters.

The use of the organic type sequestering (chelating) agents is receiving widespread interest and recognition throughout the detergent industry. These recently developed materials perform similar functions of preventing water hardness precipitation that are normally performed by the polyphosphates. The chelation agents are, however, stable to heat and are also poorly biodegradable compounds.

The two basic types of chelation agents of importance to detergent usage are: (a) the sodium salts of ethylene diamine tetraacetic acid and (b) certain other organic acid salts.

The chelation agents vary considerably in their abilities to sequester the heavy metals such as calcium, magnesium and iron, and specific agents have to be selected for particular properties. Chelation activity may be utilized during cleaning procedures by incorporating specific cleaning techniques which take advantage of this excellent detergent function.

Chlorine reacts strongly with proteins and markedly increases the effectiveness of alkaline components. Utilization of from 50 to 200 ppm chlorine increases the peptizing efficiency of alkaline detergents and also minimizes the development of mineral milkstone deposits. Observations suggest that the elimination of protein films eliminates binding sights for the build-up of mineral deposits. Chlorinated trisodiumphosphate, hypochlorides, and chloroisocuranic are commonly utilized chlorine components. The compatability of the chlorine with the basic alkali is a necessary consideration. Improper alkaline, chlorine combinations will result in the development of white deposits upon the equipment.

Chlorinated alkalis do not function as bactercidal agents because of the high pH which also minimizes the corrosive activity of the chlorine component. The chlorine content is limited to 0.01-0.02% of the cleaning solution.

Acid type cleaners are definitely established in the dairy field for milkstone removal and also as part of the cleaning process on high temperature heat exchange equipment. Such equipment as plate pasteurizers, tubular heaters and all high temperature machines now are cleaned most effectively by a two-phase circulation system, using acid type cleaner as one phase. Burned-on milk deposits are more easily removed and milkstone is prevented. Acid type cleaners are also used in can washing.

A wide choice of acid type cleaners is available. They are blends of organic acids, inorganic acids, or acid salts usually with the addition of wetting agent. To be effective an acid type detergent should produce a pH 2.5 or lower in final use solution. It should work well in hard as well as soft water and should show a minimum of corrosion on dairy metals. Inorganic acids include muriatic acid, sulfuric acid, and phosphoric acid, whereas organic acids include acetic acid, lactic acid, hydroxyacetic acid, citric acid, levulinic acid, and tartaric acid.

BOD$_5$ of Detergent Components: Selected compounds used in the manufacture of detergents and related compounds and their contribution to BOD$_5$ in pound/pound of products are shown in Table 39. Wetting agents and surfactants vary widely in BOD$_5$ values, ranging from 0.05 to 1.20. The components (*) used most commonly in dairy food plant detergents average 0.65 pound of BOD$_5$/pound. Nonionic wetting agents exhibit a low BOD, with an average value of 0.2 pound of BOD/pound of surfactant. Acids, which are used as dairy food plant detergents, usually contain surfactants in addition to organic acids, with BOD$_5$ values ranging from 0.25 to 0.85. The most common acid detergent used in cleaning dairy food plant equipment has a BOD value of 0.65 pound BOD$_5$/pound of detergent.

The amounts of various detergent components used in cleaning various types of dairy food plants by hand and CIP methods was calculated from data supplied by detergent manufacturers. The data are listed in Table 40 in pound per 1000 pounds of milk processed. Alkali, as sodium hydroxide, is the major component, ranging from 0.23 to 1.52 pounds per 1000 pounds of milk processed for hand cleaning and from 0.23 to 0.47 for CIP. Phosphate values ranged from 0.05 to 0.76 and from 0.04 to 0.21 for CIP and hand cleaning, respectively. Acid ranged from 0.08 to 0.84 for hand cleaning and from 0.07 to 0.15 for CIP; whereas surfactant was the component used in lowest concentrations, with amounts per 1000 pounds of milk processed ranging from 0.02 to 0.11 and 0.02 to 0.11 for CIP cleaning. Ice cream plants utilized the highest concentrations of detergents, with the least difference between hand and CIP cleaning procedures. This reflects the relatively large amount of equipment in ice cream plants that is still cleaned by hand, and the fact that CIP is limited to pipelines and storage tanks.

Only acids and surfactants contribute BOD to the waste water. The amount of BOD$_5$ in the waste water in pound per 1000 pounds processed for materials commonly used in dairy food plant detergents as a function of concentration used is in Figure 7. Under average conditions in a modern milk plant, the amount of BOD contributed from surfactant and acid

Table 39 - BOD_5 of Materials Used in the Manufacture of Detergents,* Sanitizers and Lubricants

Trade Name	Chemical Composition	Pound BOD_5/Pound Product
Alkamine C	Fatty amide condensate	0.45
Avitex R	High alkyl amine	0.05
Bio-Met M-100	Sodium alpha sulfo methyl myristate	0.23
**Carboxymethylcellulose	Sodium alpha sulfo methyl myristate	0.25
Condensate C	Fatty amide	0.53
Condensate PC	Fatty amide condensate	0.24
Dianol AC-100	Modified amine condensate	0.40
**Dowicide A	O-phenol phenol	1.38
**Duponol D Pastes	Aklyl alcohol sulfonate	0.45
Duponol WA QE	Alkyl alcohol sulfonate	0.76
Duponol	Long chain alcohol sulfonate	0.33
Emkane Hal	Alkylaryl detergent	0.001
Energetic	Polyoxyethylene ester of a fatty acid	0.12
Exol X 144	Detergent	0.78
Experimental 377	Detergent	0.12
Forgl 100	Nonionic fatty alcohol	0.70
**70% Hydroxyacetic Acid	$HOCH_2COOH$	0.07
**Hydroxy ammonium sulfate	$(NH_2OH)_2SO_4$	0.04
Iberscour	Detergent	0.53
**Igepal	Polymerized ethylene oxide alkyl phenol condensation product	0.04
**Igepal CA-630	Polymerized ethylene oxide alkyl phenol condensation	0.13
**Igepal CA, extra high conc.	Polymerized ethylene oxide alkyl phenol condensation	0.07

Table 39 - Continued

Trade Name	Chemical Composition	Pound BOD_5/Pound Product
**Igepal CO, 630	Phenoxypolyoxyethylene	0.005
**Igepon AP-78	Oleic ester of sodium isothionate	1.21
Ivory Snow	Sodium salt of fatty acid	1.22, 1.41
Kalex	Sodium salt of ethylene diamine tetraacetic acid	0.02
Kreelon 8D	Sodium alkylarylsulfonate	0.15
Kreelon 8G	Sodium alkylarylsulfonate	0.23
Lux	Sodium salt of fatty acid	1.47
Maprofix LK	Sodium lauryl sulfate	0.99
**Nacconol NR	Sodium alkylarylsulfonate	0.004
**Nacconol NRSE	Sodium alkylarylsulfonate	0
NAP	Blend of nonionic and anionic lubricants	0.557
Nekal NF	Alkylarylsulfonate with organic solvent	0.12
Naxonate	Sodium xylene sulfonate	0.004
**Neutronyx 600	Aromatic polyglycol ether	0
**Nonionic Surfactant #639443	Surfactant	0.004
**Nopco 1111	Sulfonated coconut oil	0.96
**Nopco 1656	Soluble fatty ester	0.12
**Nopcolube 55	Synthetic wax	0.80
**Norane W-1	Wax emulsion	0.70
**Norane W-2	Metal organic dispersion	0.01
Pentex	Emulsifying agent	0.35
**Pine Oil	Pine oil	1.08
Rinsol	Detergent	0.72
Rome Salt Flakes	Sodium salt of fatty acid	1.22
Sandopan TLF	Sulfonated fatty amide	0.05
**Sodium Alginate	Size, thickening agent	0.36

Table 39 - Continued

Trade Name	Chemical Composition	Pound BOD_5/Pound Product
Super Suds	Sodium salt of fatty acid	0.97
Synthetic Detergent (syndet)	Amine condensate	0.12
**Tallow	Tallow	1.52
**Triethanolamine	$(HOCH_2CH_2)_3N$	0.01
Triton 770	Alkylarylpolyester sulfate	0.09
Triton 771, conc.	Polyester sulfate	0.50
Triton X-100	Alkylarylpolyether alcohol	0.0015, 0.002
Tween 80	Sorbitor monooleate poly-oxyalkylene	0.35
**Ultrawet DS	Sodium alkylarylsulfonate	0
**Ultrawet 60L	Sodium alkylarylsulfonate	0.0024
**Ultrawet 35K	Sodium alkylarylsulfonate	0
**Unico Scour M	Alkylnaphthalene sulfonate	0.10
Vel	Sulfated monoglyceride of coconut fatty acid	0.27
Wixyn	Fatty acid amide	0.10
Wooncopen CMD	Coconut oil fatty amide	0.18
Xylol Scour Special	Detergent	0.42
Zalon	Fatty amide	0.20
Zipsuds	Soap "break"	0.56
Citric Acid	$CH_2COOH\ C(OH)COOH$	0.40
Ethylene Glycol	$HOCH_2 \cdot CH_2OH$	0.70
Kerosene	Long chain hydrocarbons	0.53
Lactic Acid	$CH_3CHOH\ COOH$	0.72
Lactose	$C_{12}H_{22}O_{11}-H_2O$	0.57
Methylcellosolve	Ethylene glycol mono-methylether	1.10
New Oxydol		0.15

Table 39 - Continued

Trade Name	Chemical Composition	Pound BOD_5/Pound Product
Palmitic Acid	$C_{15}H_{31}COOH$	1.07
Propionic Acid	C_2H_5COOH	0.78
Sodium Citrate	Sodium salt of citric acid	0.37
Sodium Oleate	$C_{17}H_{22}COONa$	1.36
Sodium Propionate	C_2H_5COONa	0.50
Stearic Acid	$C_{17}H_{35}COOH$	1.44
Succinic Acid	$HOOC(CH_2)_2COOH$	0.48
**Tartaric Acid	HOOCCHOHCHOHCOOH	0.30
Tide		0.15
Valeric Acid	C_4H_9COOH	1.06

---

*From American Dyestuff Reporter, August 1966, pp. 39-42.
**Used in dairy detergents and sanitizers.

Table 40 - Coefficients of Components of Cleaners and Sanitizers, Pound/1000 Pound Milk Processes

Product	Pound/1000 Pound Milk Processed in Following Types of Plants									
	Market Milk		Butter		Cheese		Condensed and Powder		Ice Cream	
	Hand	CIP	Hand	CIP	Hand	CIP	Hand	CIP	Hand	CIP
Alkali (NaOH)	0.77	0.25	0.79	0.25	0.65	0.41	0.23	0.21	1.52	0.47
Phosphate (hexa-meta PO4)	0.12	0.05	0.76	0.15	0.38	0.07	0.046	0.04	0.22	0.22
Surfactant (ARS)	0.08	0.02	0.25	0.08	0.08	0.05	0.02	0.02	0.11	0.11
Acid (hydroxyacetic)	0.84	0.15	0.35	0.10	0.14	0.09	0.088	0.07	0.52	0.15
Chlorine (NaOCl)	0.34	0.10	0.14	0.08	0.08	0.03	--	--	0.37	0.13

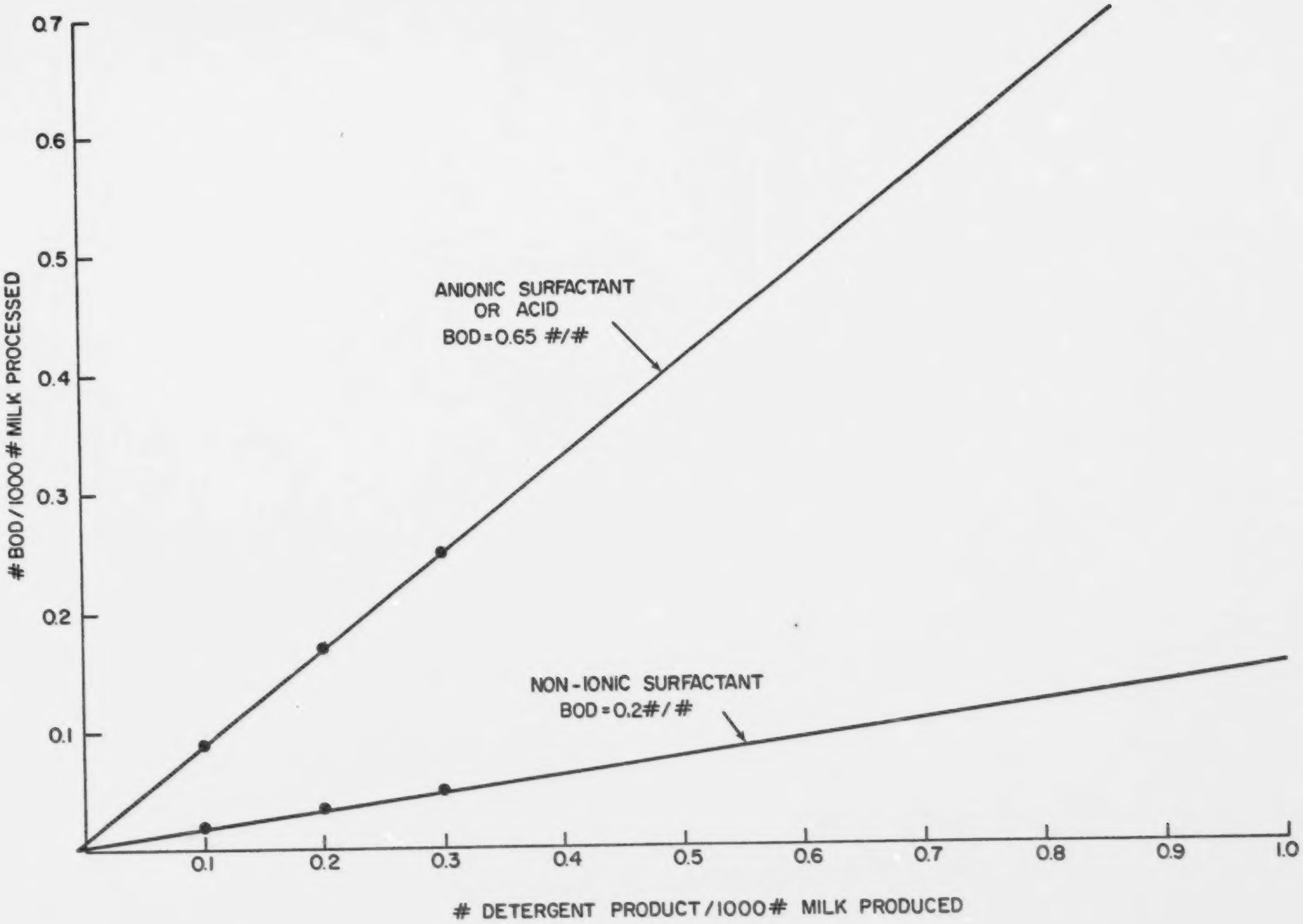


Figure 7 - Pounds BOD_5/1000 pounds of milk processed for average surfactants and acids in dairy food detergents

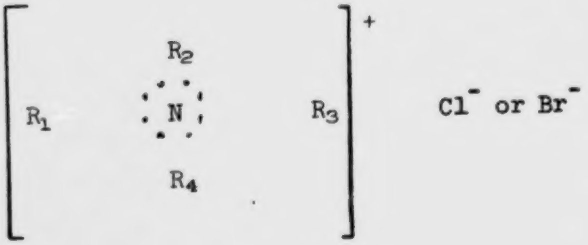
detergent would be about 0.1 pound/1000 pounds of milk processed, and about 0.2 pound of BOD/1000 pounds of milk processed into ice cream. The later value reflects a high reported acid usage in ice cream plants. At a waste water coefficient of 1.0, this would amount to a BOD_5 of 100 and 200 ppm for milk and ice cream plants, respectively; and a COD of 150 and 300 ppm for the milk and ice cream operations. The organic acid appears to be the major source of BOD and could be substituted by an inorganic acid. However, the major inorganic acid of choice would be phosphoric acid, which would add to phosphate pollution.

Sanitizers: Little is known of the role of sanitizers in dairy food plant wastes, but they are a major source of chlorine and may be a significant source of toxic materials in dairy food plant waste waters.

Sanitizers include chlorine compounds, iodine compounds, quaternary ammonium compounds, acids and phenolics. In dairy food plant sanitation chlorine and iodine compounds are most commonly used, quaternary ammonium compounds are used to a limited extent, acids are used in certain applications and phenolics are not used at all.

The types of chlorine compounds used in dairy food plants, their chemical structure and solubility are presented in Table 41. The inorganic sodium hypochlorite is the most commonly used sanitizer in the dairy food industry. Organic chlorine compounds are used as sanitizers; the chlorine compound of choice in chlorinated alkali cleaning compounds being chlorocy anurates which may be the most toxic material in dairy food plant waste water. The significance of these materials in dairy waste treatment systems remains to be determined. Trichlorcyanuric acid was used in the detergents which gave waste waters with a BOD:COD ratio of less than 0.2 during cleaning in one dairy plant (previously given in this report).

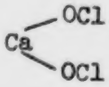
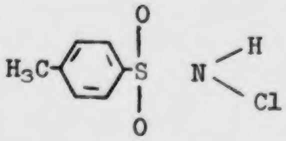
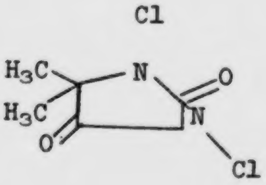
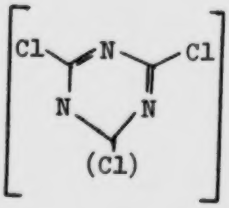
Quaternary ammonium compounds have the general formula:



$$\left[R_1 \quad \overset{R_2}{\underset{R_4}{:\!N\!:}} \quad R_3 \right]^+ Cl^- \text{ or } Br^-$$

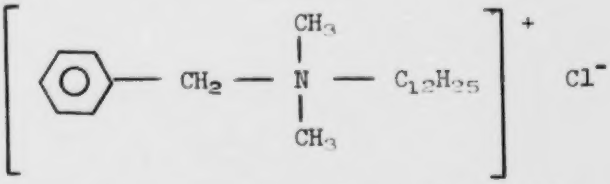
where R is a carbon compound

Table 41 - Classes of Available Chlorine Compounds

Compound	Structure	Solubility
Inorganic		
Gaseous chlorine	Cl : Cl	0.76 g/100 g
Calcium hypochlorite		6.9 g/100 g (produces sludge)
Sodium hypochlorite	Na—OCl	
Organic		
Chloramine T		15 g/100 g 1.2 g/100 g
Dichlorodimethyl Hydantoin		
Dichlorocyanuric acid		2.6 g/100 g (sodium salt is 10 x as soluble)
Trichlorocyanuric acid		1.2 g/100 g

Many forms of quaternary ammonium compounds are available, including:

1. Alkyldimethylbenzyl ammonium chloride (Ster Bac, Tri Bac, Roccal D-S)



2. Methyldodecyl benzyltrimethyl ammonium chloride

3. Lauryldimethylbenzyl ammonium chloride

4. Alkyltolylmethyl trimethylammonium chloride

5. Didodecenyldimethyl ammonium chloride

6. Paradiisobutylphenoxycthyldimethyl benzyl ammonium chloride

The most commonly used iodine sanitizers are a combination of nonionic wetting agents plus iodine, such as:

1. Polyethoxy polypropoxy ethanol - iodine complex (nonionic wetting agent and iodine)

2. Polyethoxy polypropoxy ethanol with nonyl phenylether of polyethylene glycol-iodine complex (Iobac, Iosan, Wescodyne, Mikro-Klene, IODE, Iodophor, Mon-O-Dine)

Acid sanitizers employ phosphoric acid and anionic wetting agent at concentrations of 0.3 to 0.5% to give a pH < 2.5.

Recommendations for concentrations, exposure times and percentage of available chlorine for various common types of sanitizing agents are presented in Table 42 on the following page. Active ingredients must be stated on all sanitizer labels, but percentage available chlorine may or may not be stated. Iodophors contain about 10% anionic or nonion wetting agent and have a BOD_5 of about 0.05 pound/pounds of sanitizer.

Contribution of Detergents and Sanitizers to Dairy Food Plant Waste Water From Industrial Plants

Where information was available for the amount and composition of detergents and sanitizers used in the 56-plant survey in this study, it was possible to calculate the percentage of cleaning and sanitizing solutions in the waste water and to calculate the ppm of major components, including akali, phosphate, acid and chlorine. Data for 27 plants are summarized in Table 43. The cleaning solution, as percentage of waste

Table 42 - Recommended Concentrations and Time of Exposure*

Chemical	Concentration ppm	Spray and Fog, ppm	Percent Available Chlorine
CHLORINE			
Sodium hypochlorite	100	200	100
Calcium hypochlorite	100	200	100
Dichloroisocyanuric acid	100	200	70
Trichloroisocyanuric acid	100	200	90
Potassium dichloroisocyanurate	100	200	59
Sodium dichloroisocyanurate	100	200	60
Chloramine T (pH 7.0)	250	400-500	25
Chloramine T (pH 8.5)	250	400-500	25
Hydantoin (Acid pH)	200	400	66
QUATERNARY AMMONIUM COMPOUNDS			
pH 6.0 or higher at 75°F or higher	200	400	-
IODINE			
Nonionic wetting agents + iodine	12.5	400	-
BROMINE-CHLORINE	25	75	-
ACID-ANIONIC	200	400	-

*Manufacturers' recommendations

Table 43 - Contribution of Detergents and Sanitizers to Dairy Food Plant Waste Waters

Plant No.	Product Produced	Percentage of Waste Water as:		ppm of the Following Components in Waste Water					
		Cleaning Solution	Sanitizer	Cleaning Solution	Sanitizing Solution	Alkali	Phosphate	Acid	Chlorine
1	Milk	20.8	5.0	208,000	50,000	674.8	51.5	347.8	204.9
5	Milk	3.4	0.59	34,000	5,900	32.2		4.0	6.7
35	Cheese	22.5	6.28	225,000	62,800				52.6
38	Cheese	4.66	5.0	46,600	50,000				
23	Ice Cream	2.2	0.5	32,000	5,000	43.0	19.1		24.4
24	Ice Cream	2.15	0.2	21,500	2,000	42.9	47.9	10.3	9.2
26	Ice Milk, Sherbet		2.92		29,200				
37	Cottage Cheese	17.8	9.80	178,000	98,000	150.0	75.3	64.5	234.0
6	Cottage Cheese Milk	22.0	2.0	220,000	2,000				
10	Cottage Cheese Milk	40.9		409,000	2,000	248.6	32.8	29.2	146.1
19	Cottage Cheese Milk	26.0	1.04	260,000	10,400				
28	Cottage Cheese Milk	9.1	1.82	91,000	18,200				4.1
2	Cottage Cheese Milk, Yogurt	4.50	1.15	45,000	11,500	248.0	59.0	108.3	45.3
16	Cottage Cheese Milk, Yogurt	23.8	13.8	238,000	138,000				163.7

Table 43 - Continued

Plant No.	Product Produced	Percentage of Waste Water as:		ppm of the Following Components in Waste Water					
		Cleaning Solution	Sanitizer	Cleaning Solution	Sanitizing Solution	Alkali	Phosphate	Acid	Chlorine
21	Cottage Cheese Milk, Yogurt	16.2	5.0	162,000	57,000	50.6		11.4	59.5
14	Milk, Yogurt, Sour Cream, Fruit Drink	4.25	1.03	42,500	10,300	125.4		127.9	119.5
20	Cottage Cheese Milk, Sour Cream, Fruit Drink	7.6	1.5	76,000				35.0	63.6
22	Cottage Cheese, Milk, Sour Cream, Fruit Drink	7.4	0.28	174,000	2,800	92.9		25.6	79.8
8	Cottage Cheese, Milk, Yogurt, Sour Cream	40.0		400,000		6,280			108.2
3	Cottage Cheese, Milk, Cream	22.0	2.50	220,000	2,500	135.0	32.1	56.3	40.2
17	Cottage Cheese, Milk, Ice Cream	10.0	1.40	100,000	14,000	166.9		29.2	81.5
30	Cottage Cheese Milk, Ice Cream	15.0	5.00	150,000	50,000	250	37.0	136.5	48.6
11	Cheese, Milk	17.55		175,500		136.3	30.5		22.0
12	Cheese, Milk, Fruit Drink	8.6		86,000		40.3		12.4	4.4

Table 43 - Continued

Plant No.	Product Produced	Percentage of Waste Water as:		ppm of the Following Components in Waste Water					
		Cleaning Solution	Sanitizer	Cleaning Solution	Sanitizing Solution	Alkali	Phosphate	Acid	Chlorine
7	Cottage Cheese Cheese, Milk Powdered Milk	41.6		416,000		744.0			43.0
4	Cottage Cheese Sterile Product	6.2	0.15	62,000	1,500	61.7		30.0	32.9
13	Milk, Yogurt Fruit Drink	2.91	0.75	291,000	7,500	8.4		36.0	25.1

water ranged from 2.2 to 41.6% with an average value of 15%. The sanitizer solution contributed from 0.2 to 13.8% and an average of 3.1% of the waste water. The lower the waste water coefficient for a dairy plant, the greater was the percentage of that water made up of detergents and sanitizers. The average concentration of detergent in the cleaning solution would be 5000 ppm and for sanitizers the average would be 100 ppm chlorine. In terms of the waste water, the concentration of alkali as NaOH ranged from 32 to 6280 ppm with an average of 500 ppm; phosphate ranged from 30 to 75 ppm with an average of 43 ppm; acid ranged from 10 to 348 ppm and averaged 66 ppm; whereas, chlorine ranged from 6 to 234 ppm and averaged 70 ppm.

Based on the data obtained during this investigation, it would appear that detergents and sanitizers may be much more significant in dairy wastes than previously reported (355). They potentially contribute significantly to BOD, to refractory COD and may be significant in providing toxicity and poor performance to dairy waste treatment facilities. Their affect on the dominating microflora of dairy food plant wastes and a full determination of their real significance requires further investigation.

As plants become more automated and control waste water coefficients more effectively, the contribution of detergents and sanitizers will be increasingly important in these plants waste waters.

VARIATIONS IN DAIRY FOOD PLANT WASTES

The information presented up to this point has been based on average data, and does not reflect the variability of dairy food plant wastes during a processing day, day-to-day, weekly, monthly or seasonal variations. Dairy food plant wastes have the same large variations during the processing day that characterize most food plant operations, are similar in the magnitude of the day-to-day variations, but exhibit less seasonal variations than is observed in other types of food plants. The waste load is closely related to the amount of product processed (174, 466, 1133). Knowledge of both hydraulic and strength variations are important in respect to the design and proper operation of waste treatment facilities. This is particularly true with regard to the treatment of dairy food plant wastes by municipal systems which frequently are marginally designed. Dairy plant wastes, in general, become significant in a waste treatment facility and appear to be the controlling factor, when they make up more than 50% of the total BOD of the treatment facility, or when whey contributes 10 percent of the total BOD. Whey can have marked influence on the operation of the treatment facility, especially if all of the whey is introduced at one time. No attempt will be made at this time to document all of the numerous investigations of variation, but examples will be presented to indicate the nature of the variation and the variation in various composition parameters.

Generally processing day (hour-to-hour) variations are erratic and do not give a normal distribution pattern. However, day-to-day, weekly, and monthly average values generally follow a normal variation curve, and frequently plots of such data are of value in providing indices of minimal and maximum variations of both waste volume and composition. Major attention will be given to BOD variations, since these parameters are most commonly utilized.

Variations during the Processing Day

Hourly variations during the processing day have been reported for volume (124, 374, 1289), BOD (153, 159, 374, 496, 1077), COD (159, 374, 1077), suspended solids (374, 1077), and temperature (1289, 1290). As would be expected, marked variations occur in waste water volume, temperature and waste strength during the processing day because of variability of the water requirements and waste load of variation unit operations during the day. The frequency and magnitude of variations in volume, temperature and composition is an individual plant characteristic, depending upon the nature and sequencing of the various operations and the degree of management control over the operation.

Zall (1289) investigated the variation in flow, temperature and BTU output of a small dairy plant both before and after the instigation of a waste control program. Variations before and after the initiation of the control program are shown in Figures 8 and 9, respectively. The data was collected by continuous recorders and is somewhat more precise than data based on the collection of hourly samples, which has been the basis of most studies. The frequency of fluctuation was unaffected by the control program which was associated with the sporadic nature of the operation; whereas the magnitude of the variation was decreased by a factor of 2 for both volume and temperature after waste control procedures were affected. The change was associated with the elimination of hot water contributed by hoses being left running when not in actual use; which is a major factor contributing to waste water volumes in many dairy food plants.

During this study, data for variations were obtained in several modern dairy plants with automated fluid processing and CIP. Data for hour-to-hour variations for volume and strength was obtained for two large dairy plants during this investigation. Plant A produced milk, cottage cheese and ice cream and plant B produced milk and cottage cheese. In both cases, the whey was excluded from the waste water. Values for volume, ppm BOD and pounds of BOD are shown in Figure 10 for plant A. The ppm BOD values increased from a base level with the start-up of the filling operation and remained above 1500 ppm throughout the processing day. Two major peaks of BOD (ppm) occurred in the afternoon and coincided with simultaneous emptying and cleaning cheese vats and flushing out the 50,000 lb/hr HTST unit. Peaks of waste water volume did not coincide with the BOD peaks, and could be associated with cleaning operations and increased use of cooling water. The variation in

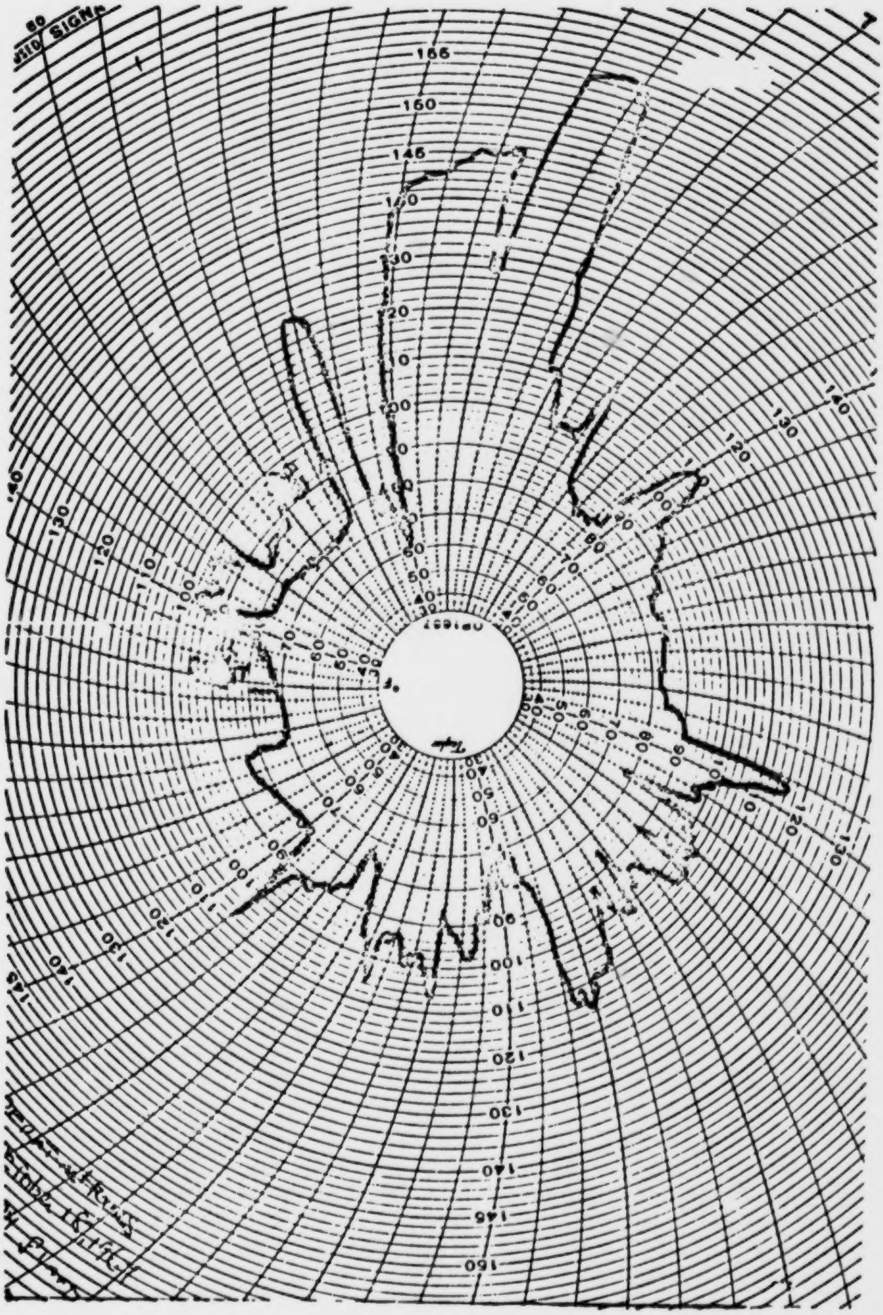


Figure 8 - Twenty-four hour recorder chart of effluent temperature on typical day before conservation practices put into effect

Reproduced from best available copy.

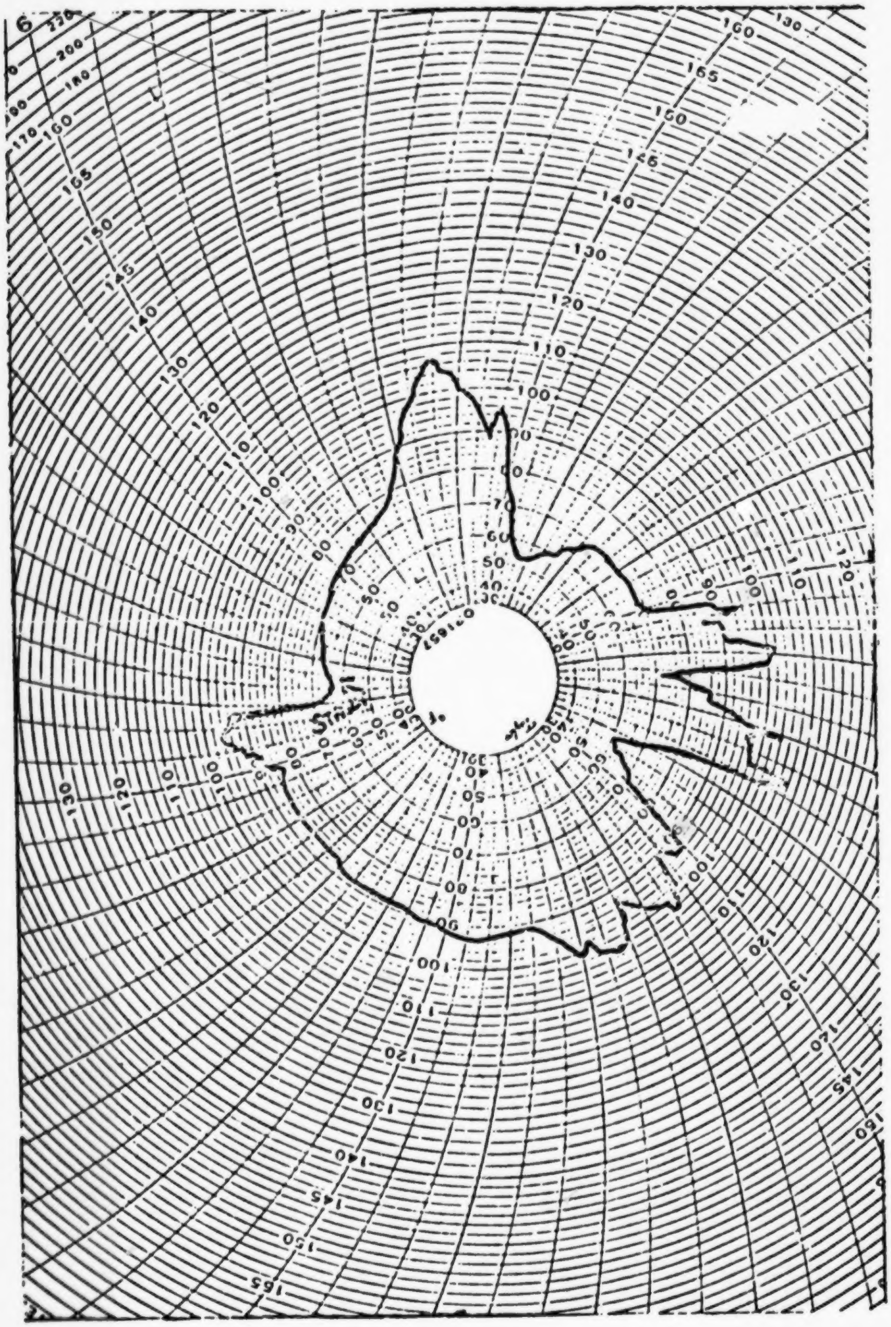


Figure 9 - Twenty-four hour recorder chart of effluent temperature on typical day after conservation practices put into effect

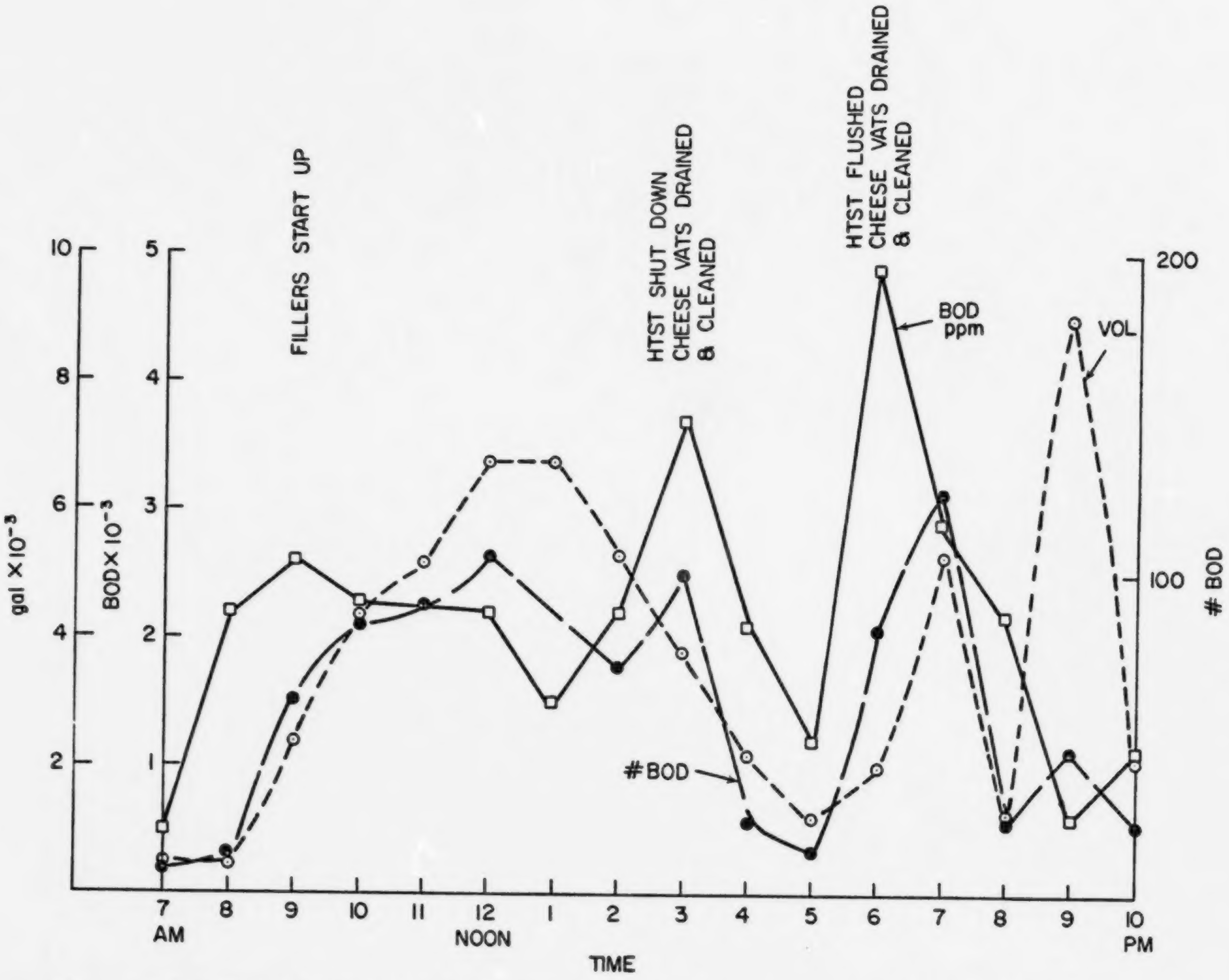


Figure 10 - Hourly variations in ppm BOD_5 pounds BOD_5 and waste water volume for dairy plant A

pounds of BOD reflected changes in both ppm BOD and water volume. The mean value for pounds of BOD was 50, with values exceeding 100 pounds three times during the day.

Data for BOD ppm, COD ppm, and volume, are presented in Figure 11 for plant B. Major peaks of BOD could be identified with start-up of the HTST unit, draining and cleaning cottage cheese vats and general clean-up of filling and processing equipment in the evening. As for plant A, peaks in waste water volume and BOD (or COD) did not coincide. As expected, the COD variation followed that of BOD. However, during the cleaning period the increase was much greater for COD than for BOD, as compared to the previous peaks associated with large loads of milk solids. Peak volumes and waste strength were more than twice the average value. On one processing day for Plant B, the peak BOD value was four times the average. In another plant (automated CIP plant manufacturing cottage cheese, milk and ice cream) the average BOD for one day's operation was 2500, with peak loads during HTST start-up being 7500 ppm BOD and during ice cream clean-up being 12,500 ppm BOD.

Figure 12 shows processing volume variation for two consecutive days based on data for McKinney and Schwinn (687); while Figure 13, a frequency diagram for this data, shows abnormal distribution as would be expected. A frequency plot of BOD and COD for the data in plant B is shown in Figure 14. An "S" shaped distribution plot is obtained, which is characteristic of the frequency distribution of dairy food plants wastes during a given processing day.

Day-to-Day Variations in Dairy Food Plant Wastes

Numerous investigators have investigated the day-to-day variations in dairy food plant wastes (159, 160, 176, 430, 929, 976, 980, 1089, 1206, 1238, 1239). However, none of these investigators have attempted to determine frequency plots or to establish the maximum volume or strength in relation to the mean value. Based on data of several investigators, frequency plots for BOD for day-to-day variation of dairy food plant waste water strength are presented in Figure 15 (159, 160, 687, 1201, 1236, 1238). Five of the six plots follow a normal distribution and show a straight relationship, whereas the sixth plot shows the "S" shaped distribution previously noted in hour-to-hour variations. Where normal distribution existed, the maximum BOD level (at a 1% confidence limit) ranged from 1.77 to 2.46 times the mean value, with an average of 2.107. The data with the abnormal distribution had a maximum value for BOD that was 3.6 times the mean value. Thus, average BOD values must be interpreted with care, and frequency plots should be made over at least a 30-day period of time to establish the variation in both BOD and volume.

Data in Figure 16 compare ppm BOD, protein and lipid values for Walgren's study (1201), in which the "S" distribution curve for BOD was presented. The frequency plot for protein was linear, whereas the frequency plot for lipid was more abnormal than that for BOD. The data

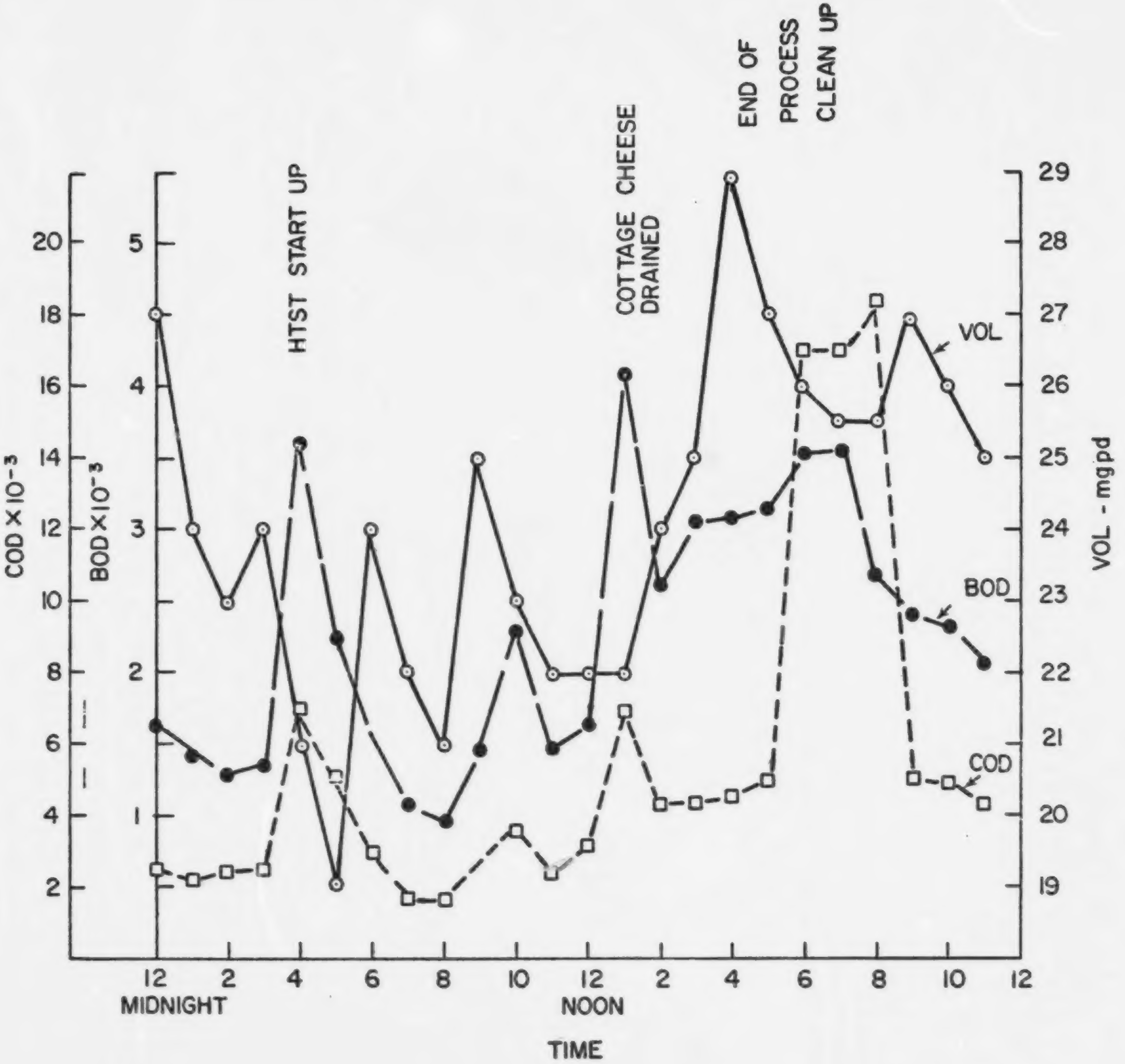


Figure 11 - Hourly variations in ppm BOD_5, COD and waste water volume for dairy plant B

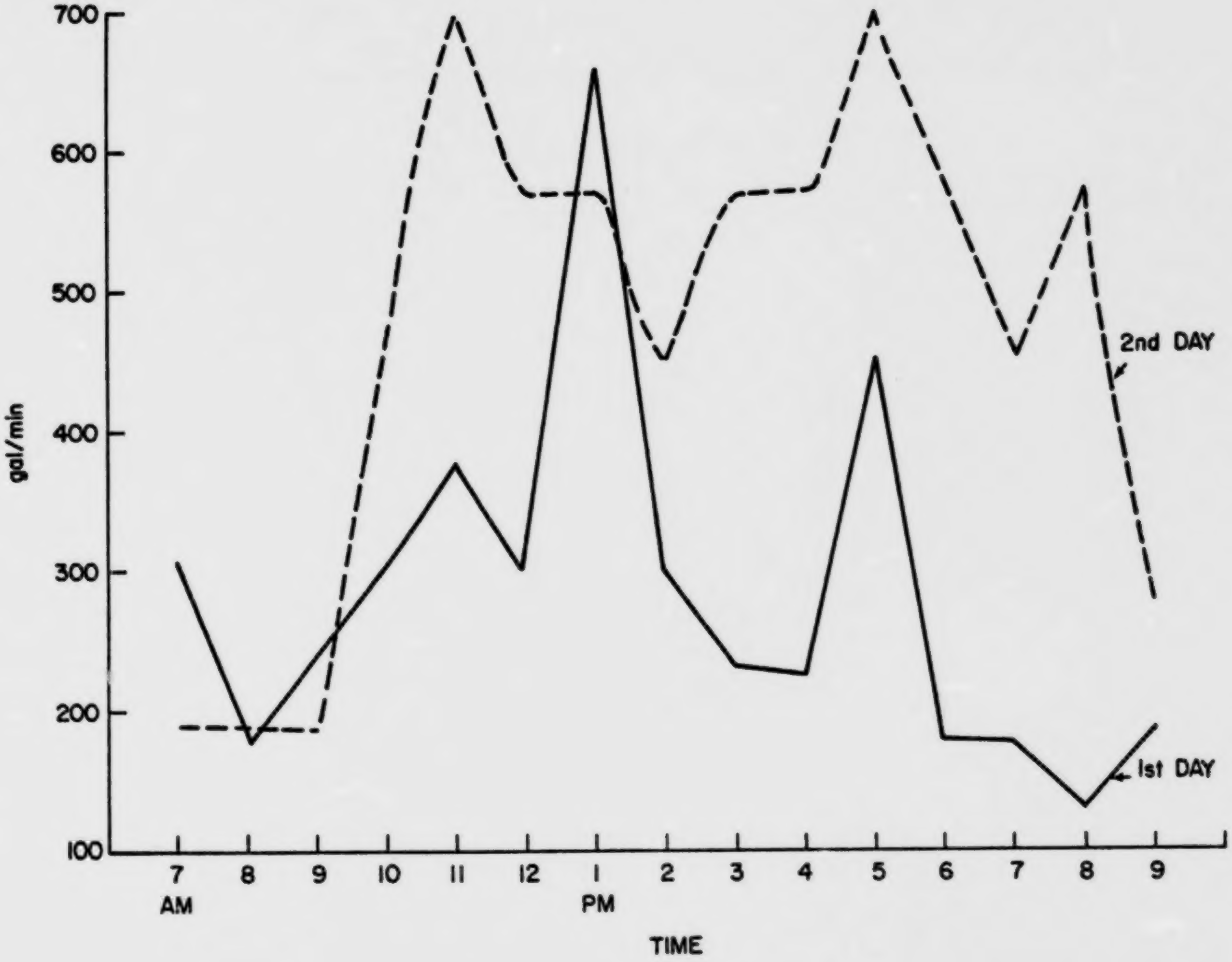


Figure 12 - Hourly variations in waste water volume for a dairy plant on two consecutive days (687)

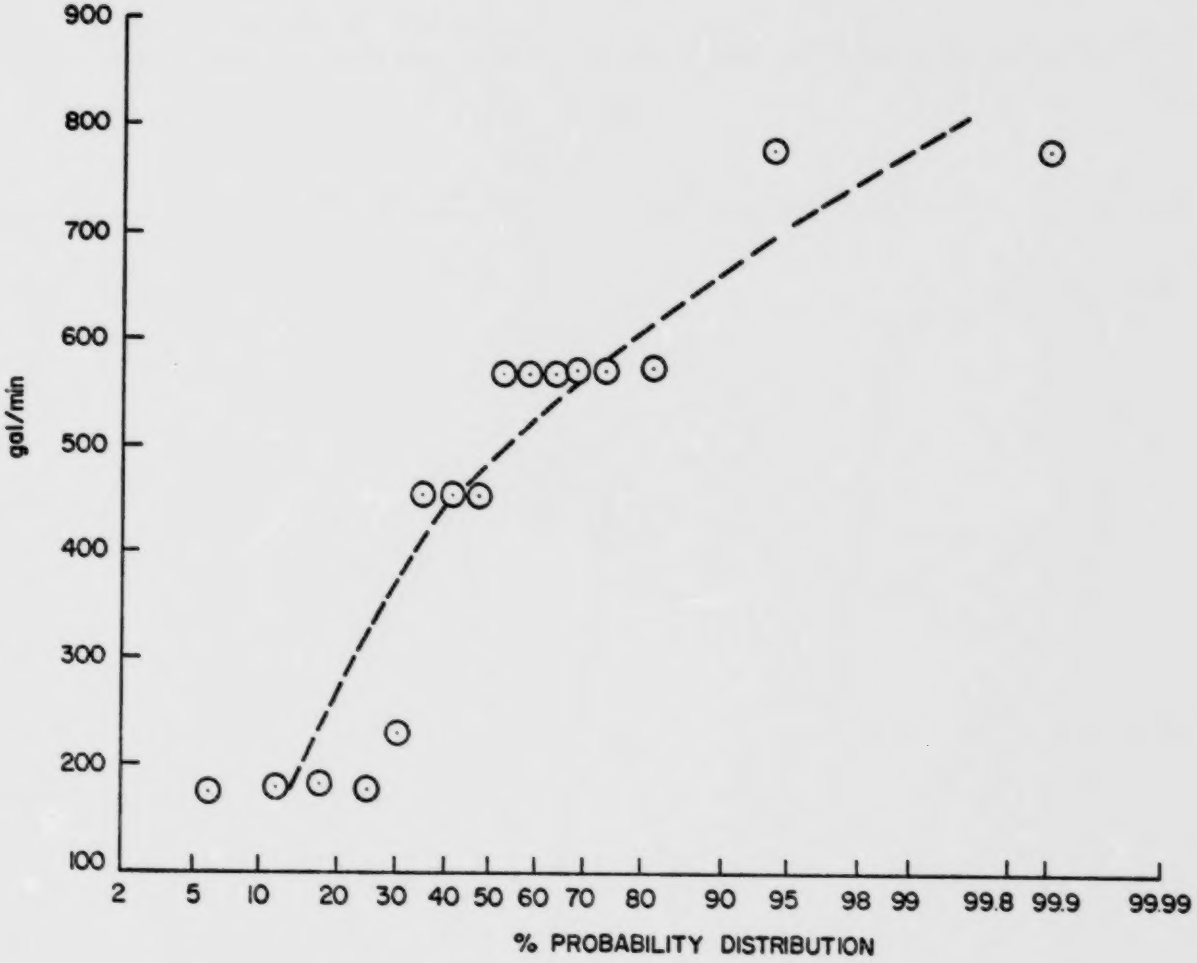


Figure 13 - Distribution of waste water volume for a processing day in one dairy plant (687)

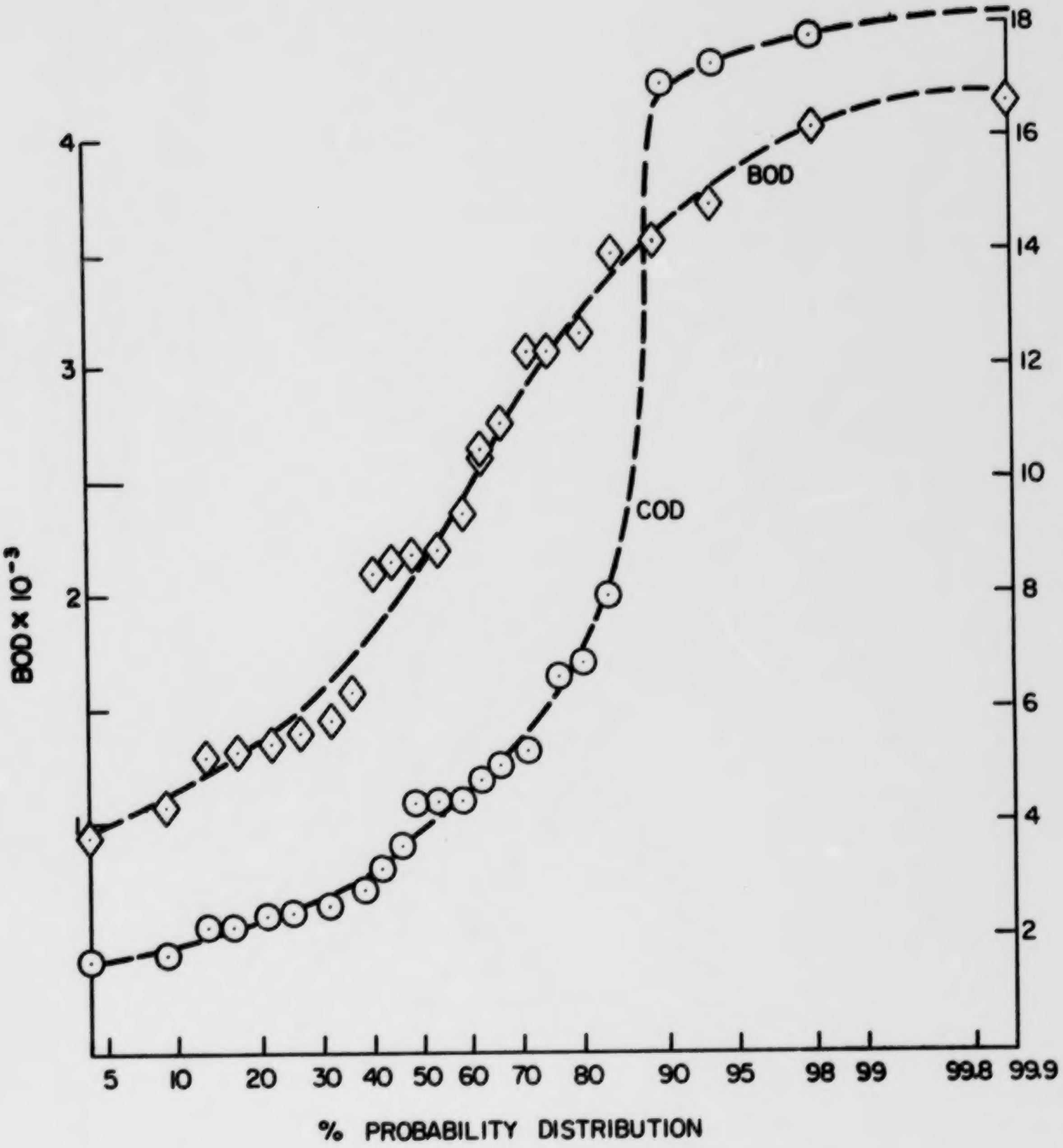


Figure 14 - Distribution of ppm BOD and COD during a one day operation of one dairy plant (1201)

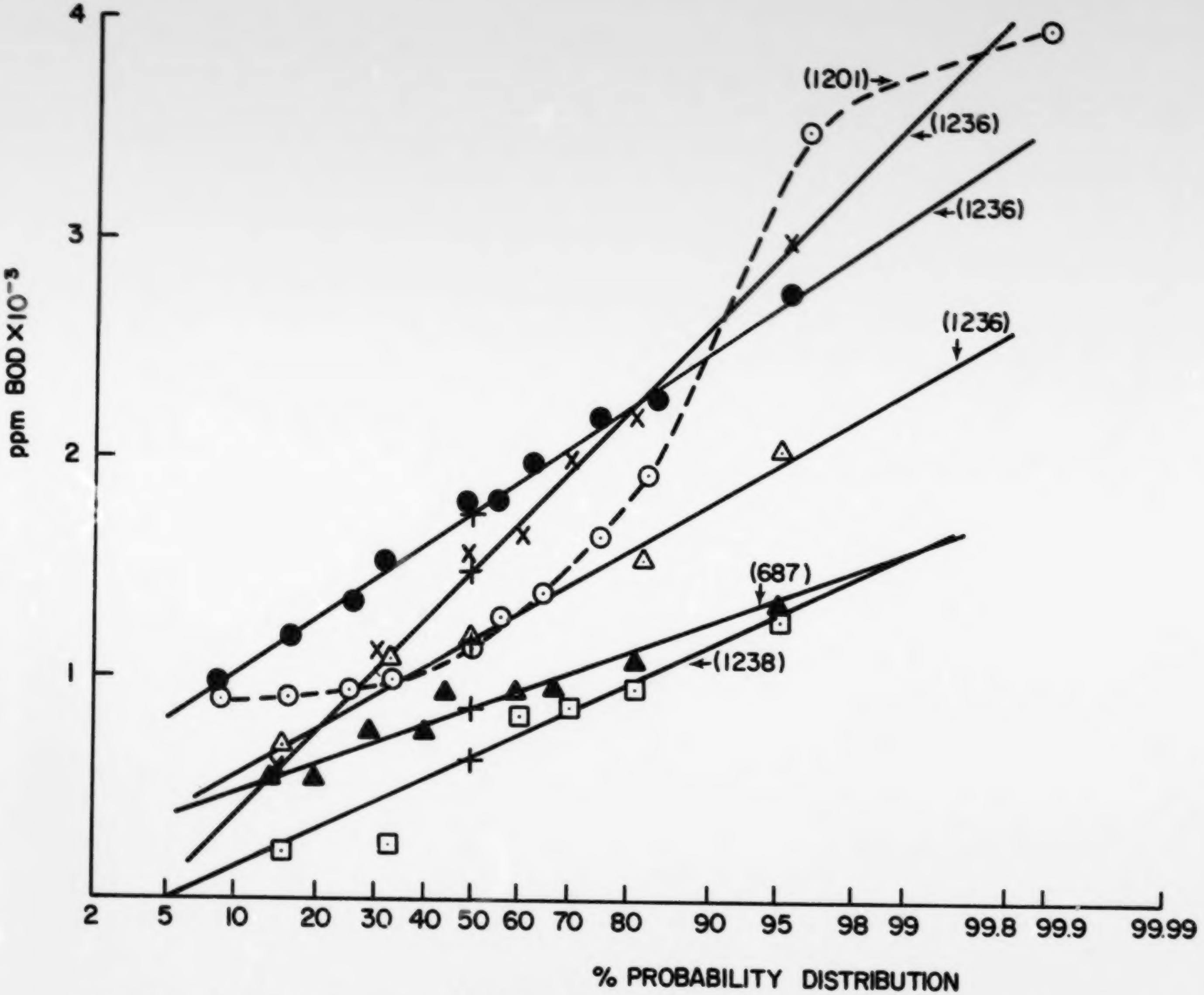


Figure 15 - Distribution of daily BOD_5 (ppm) variation in various dairy food plant waste waters (Number refers to literature reference numbers)

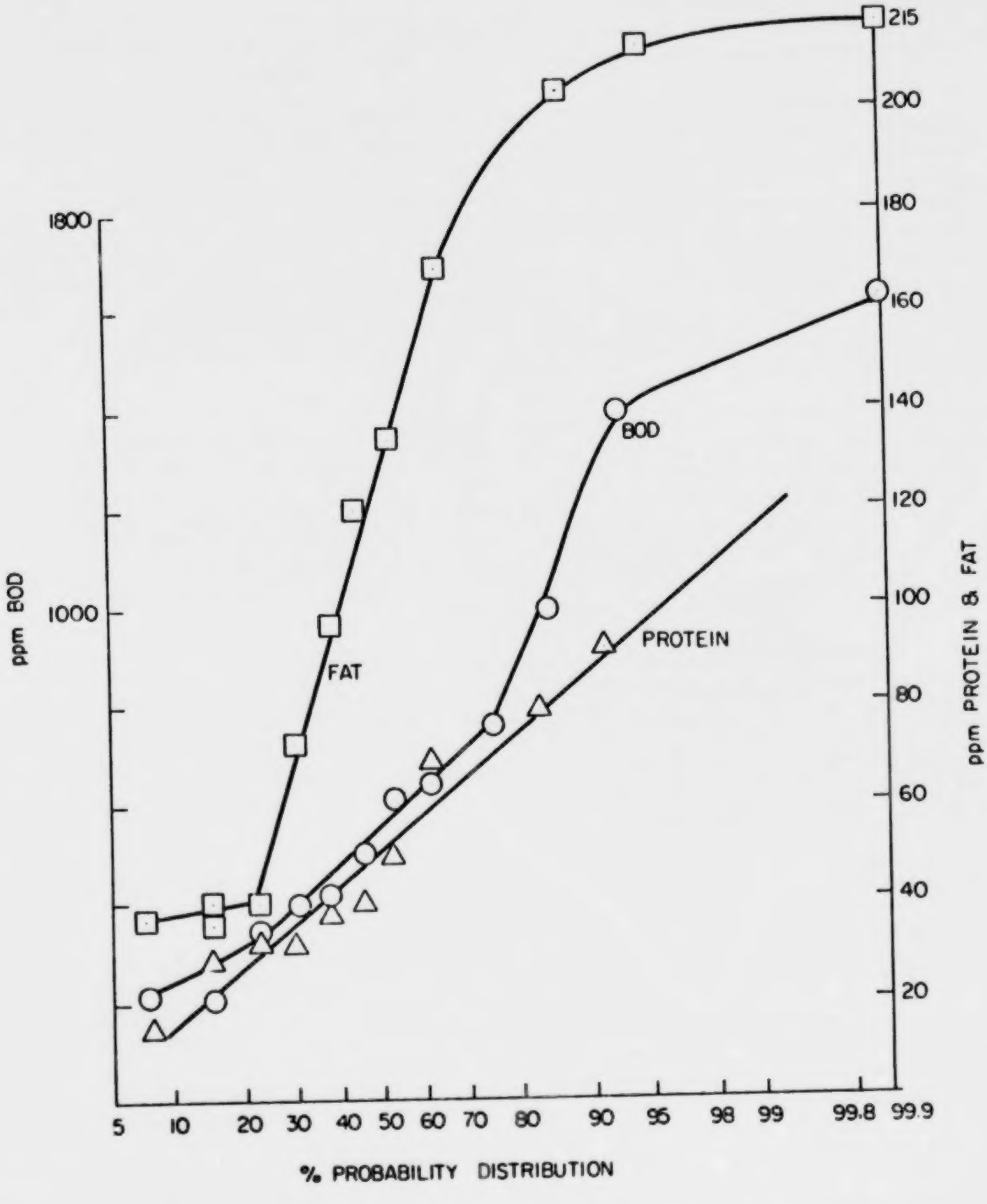


Figure 16 - Daily variation in ppm BOD_5, fat and protein for waste water from a dairy food plant (Walgren, 1968)

substantiate earlier observations of a lack of correlation between milk constituents in dairy food plant wastes and suggest that lipid is a major variant in the composition. In this cas it would appear that large day-to-day variation in fat losses, independent of other milk constituents, is the controlling factor in the ratio of BOD variation.

A comparison of day-to-day variation in ppm BOD and COD is shown in Figure 17 from the data of McKinney and Schwinn (687). Whereas in this example the BOD follows a normal distribution pattern and plots as a linear line, the COD data reveal an "S" shaped distribution curve. As COD becomes a more significant parameter for measuring the strength of dairy food plant wastes in the future, the disproportionate distribution of COD in comparison to BOD will need to be explained. Based on limited data and observation, the most probable explanation in a day-to-day variability is the variable amount of cleaning compounds used in the plant, thus emphasizing the benefits of automated CIP cleaning and detergent use control.

Examples of normal and abnormal frequency distribution plots for day-to-day variation in waste water volume are shown in Figures 18 and 19 for commercial plants B and D. Plant D, like A, B and C, is a large modern operation manufacturing market milk and cottage cheese. Based on the data presented in these two figures, literature data and other observations, the maximum water usage on a daily basis varies between 1.6 and 2.5 times the mean volume, with an average of 2.0 times the average value (at a 1% confidence limit).

Variation in pH, settleable solids, BOD, COD, total solids, total volatile solids, suspended solids and volatile suspended solids are presented in Table 44 for an eastern dairy plant (F) manufacturing milk and cottage cheese. The data for ppm BOD and COD are plotted in a frequency diagram in Figure 20. Both show a similar skewed distribution on both low and high sides of the mean. The lowest value can be accounted for by a nonprocessing day.

Suspended solids for two other plants (D and E) are shown in Figures 21 and 22; a pH variation for plant E is shown in Figure 23.

Monthly variations: As more data are averaged, it would be expected that observed variations in dairy food plant wastes would become more normal in their distribution and that the magnitude of the variation would increase. Figure 24 presents data for plant B in respect to hourly, daily, and monthly variation in BOD. In no case in the literature or in industrial data was there any indication of abnormal frequency distributions on monthly averages, as might be expected. Frequency plots for monthly averages for the most recently available data is given for plants B, C, C, and E, in Figure 25. The values are almost all similar in slope, with an average of 2.5 times the mean value being a measure of the maximum BOD, at a 1% confidence limit.

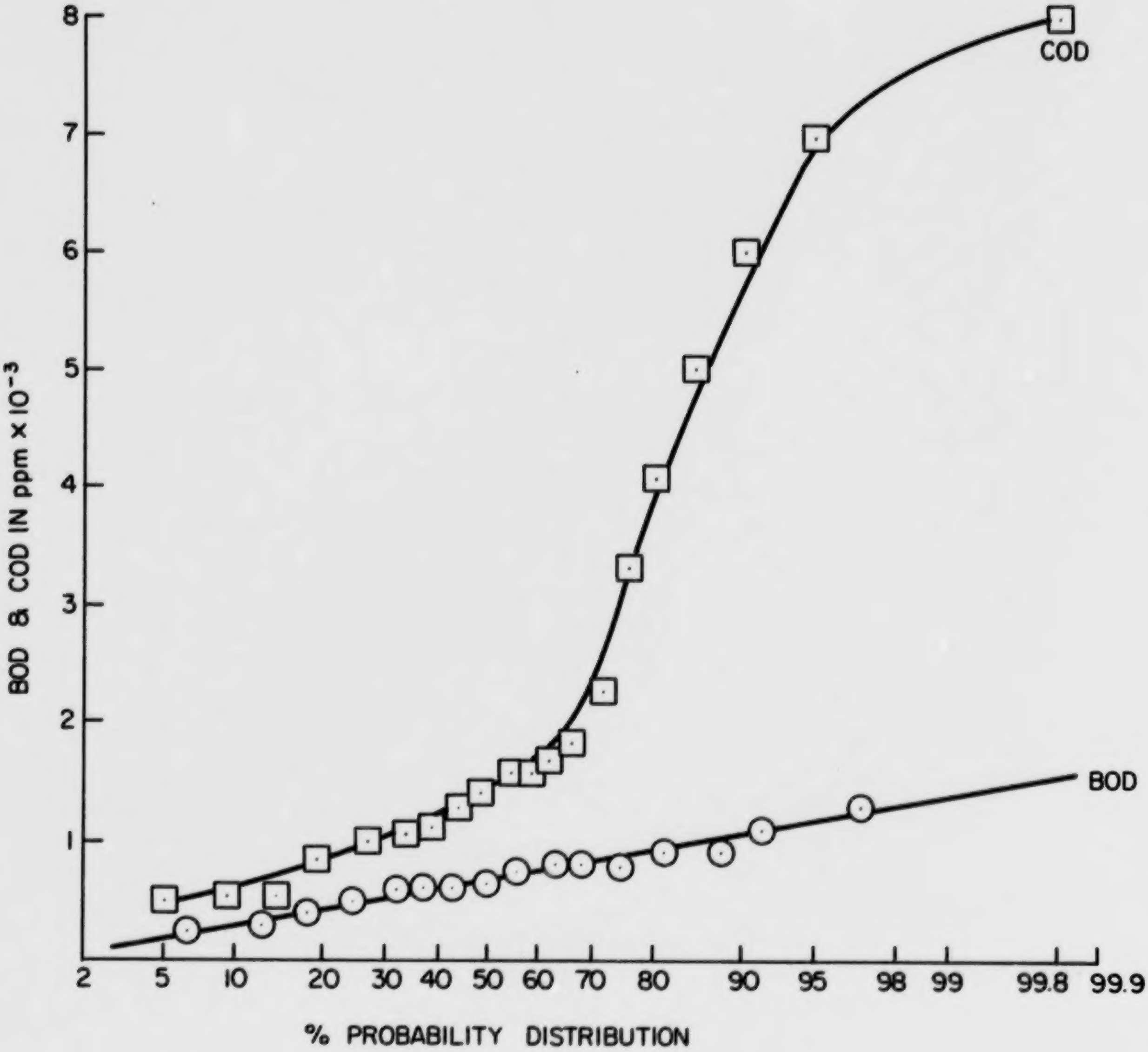


Figure 17 - Daily variation in BOD_5 and COD for waste water from a dairy food plant (McKinney and Schwin, 1960)

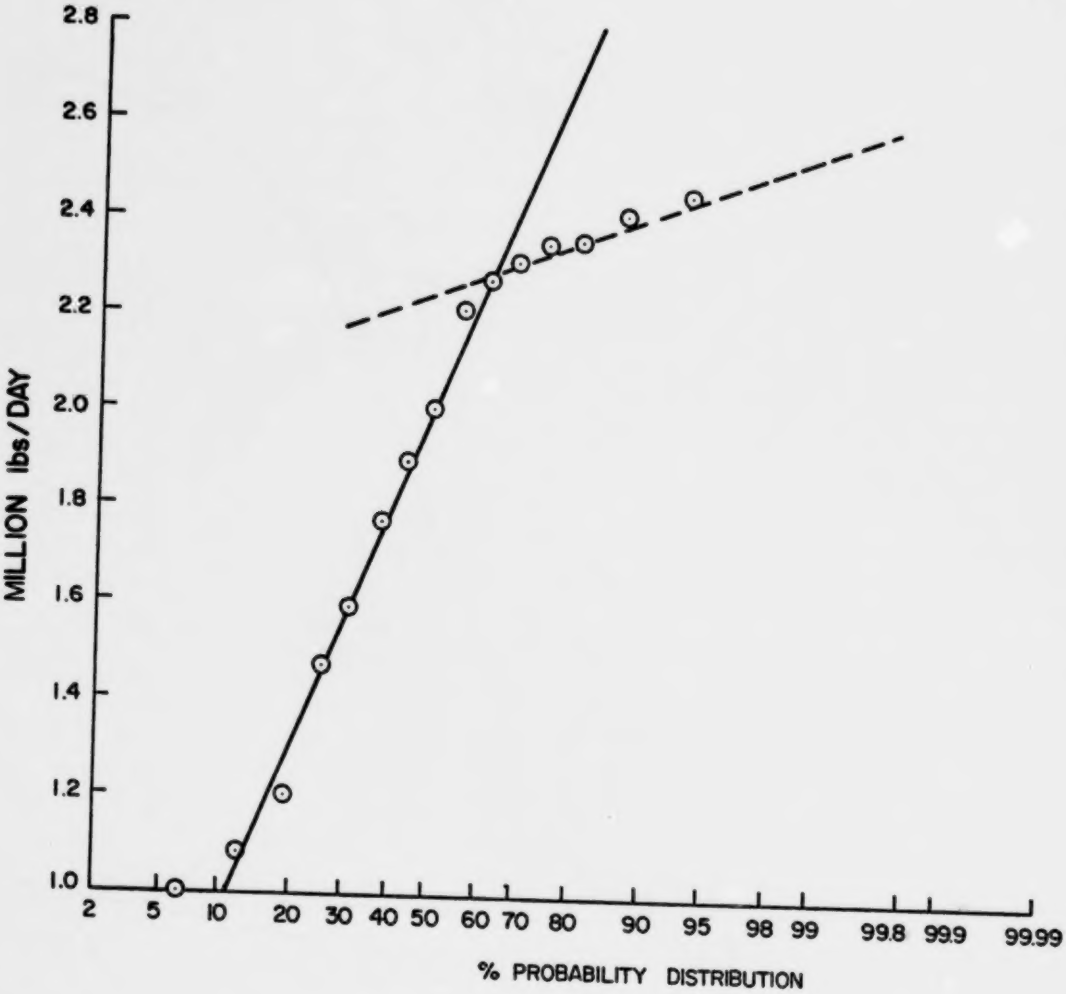


Figure 18 - Variation in daily waste water dischared by Dairy Food Plant B

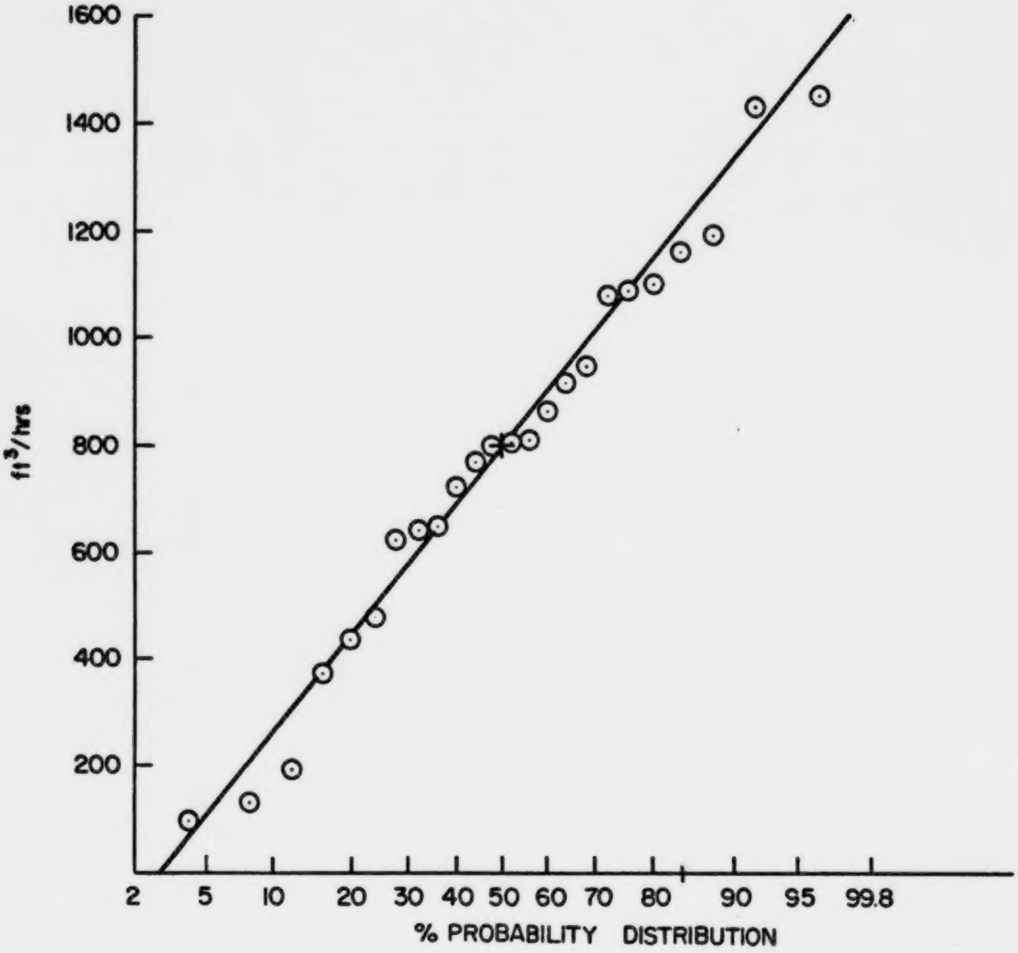


Figure 19 - Variation in daily waste water volume discharged by food plant D

Table 44 - Dairy Variations in Waste Water Characteristics for a Commercial Food Plant (F) Manufacturing Milk and Cottage Cheese

Day	pH	Settleable Solids, mℓ/ℓ	BOD 5-Day	COD	Total Solids	Total Vol. Solids	Suspended Solids	Volatile Suspended Solids
1	6.70	5.0	1300	1700	1825.3	1468.2	312.6	293.5
2	6.85	4.5	1000	1700	1631.5	1293.6	240.8	228.3
*3	7.31	0.3	150	400	335.4	224.4	61.5	56.4
4	6.00	1.1	2100	3700	3186.7	2704.6	262.8	252.7
5	7.00	2.8	1100	2100	1782.9	1443.6	292.0	10.5
6	6.70	3.0	1500	2600	2077.7	1700.5	311.4	10.2
7	6.70	4.5	1500	2400	2121.9	1710.2	336.1	12.0
8	6.80	1.5	1500	2500	2266.9	1849.2	290.0	11.5
9	6.80	1.7	1200	2300	2167.7	1756.4	324.1	11.2
10	7.00	1.0	1500	2100	2400.8	1953.0	347.4	21.0
**2	4.85	-	52	0	94.2	43.4	6.1	1.1
**9	4.00	-	64	200	126.7	66.3	6.7	3.1

*Nonprocessing day
**Cooling water

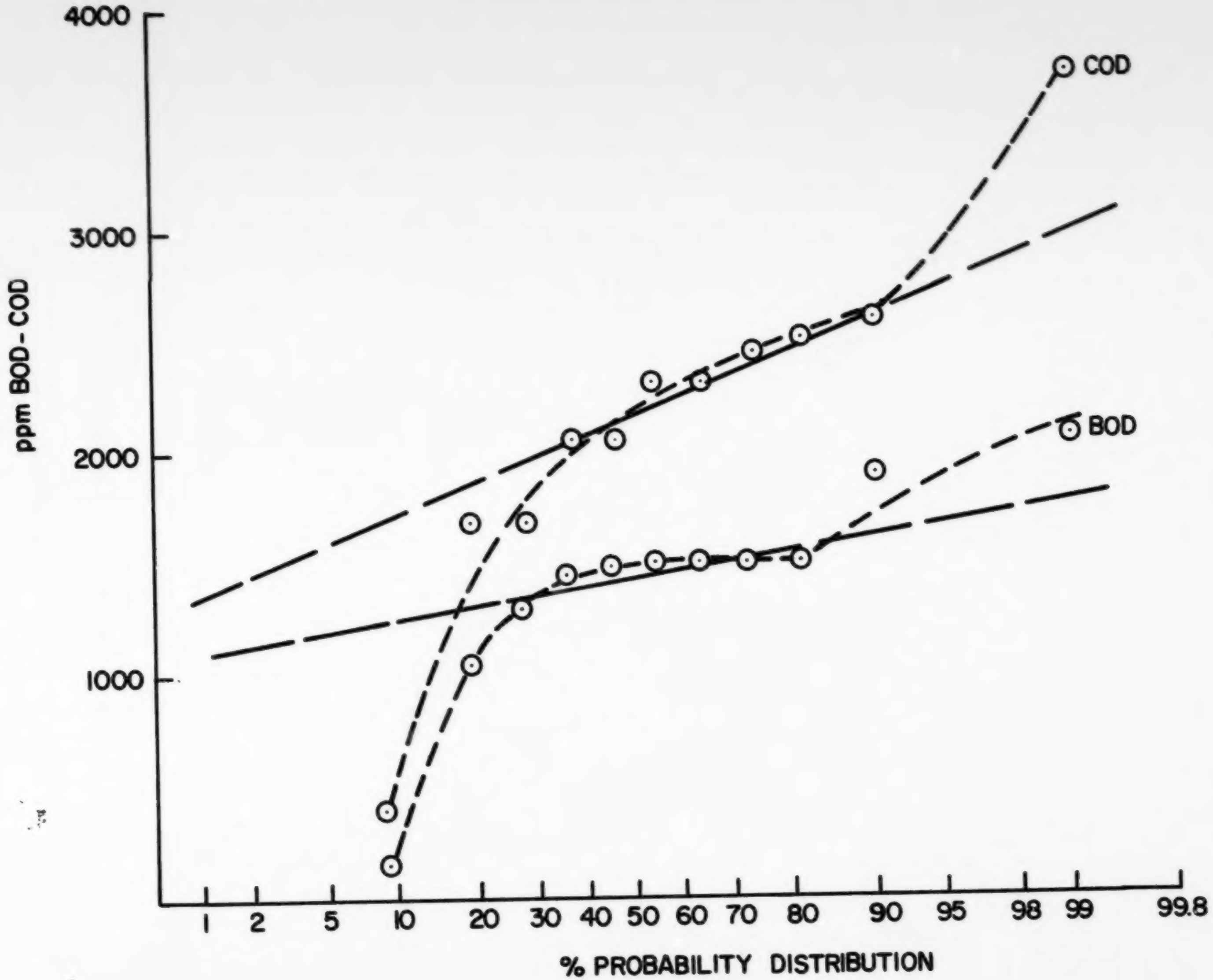


Figure 20 - Daily variation in BOD_5 and COD for dairy food plant F

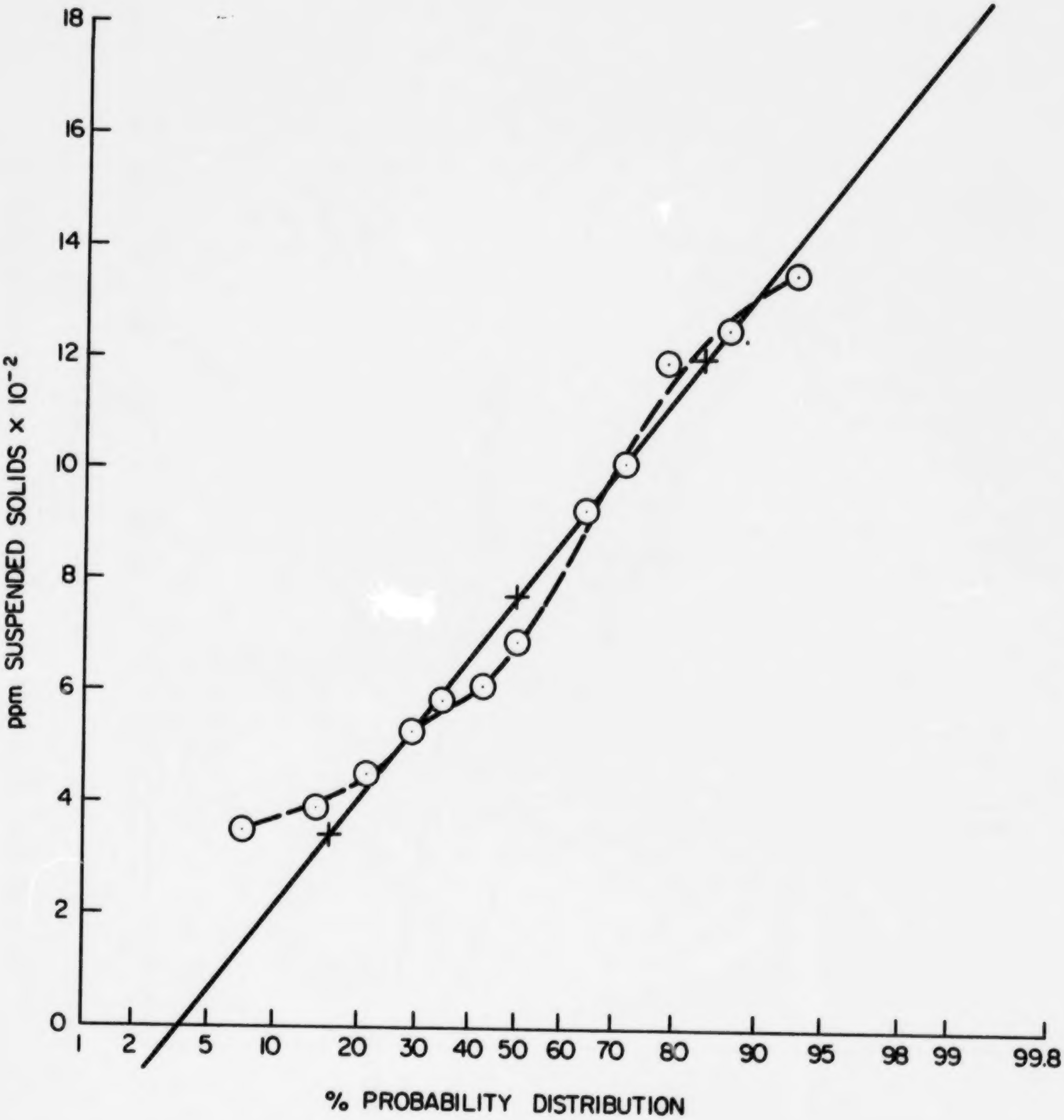


Figure 21 - Daily variation in suspended solids in waste water from dairy food plant D

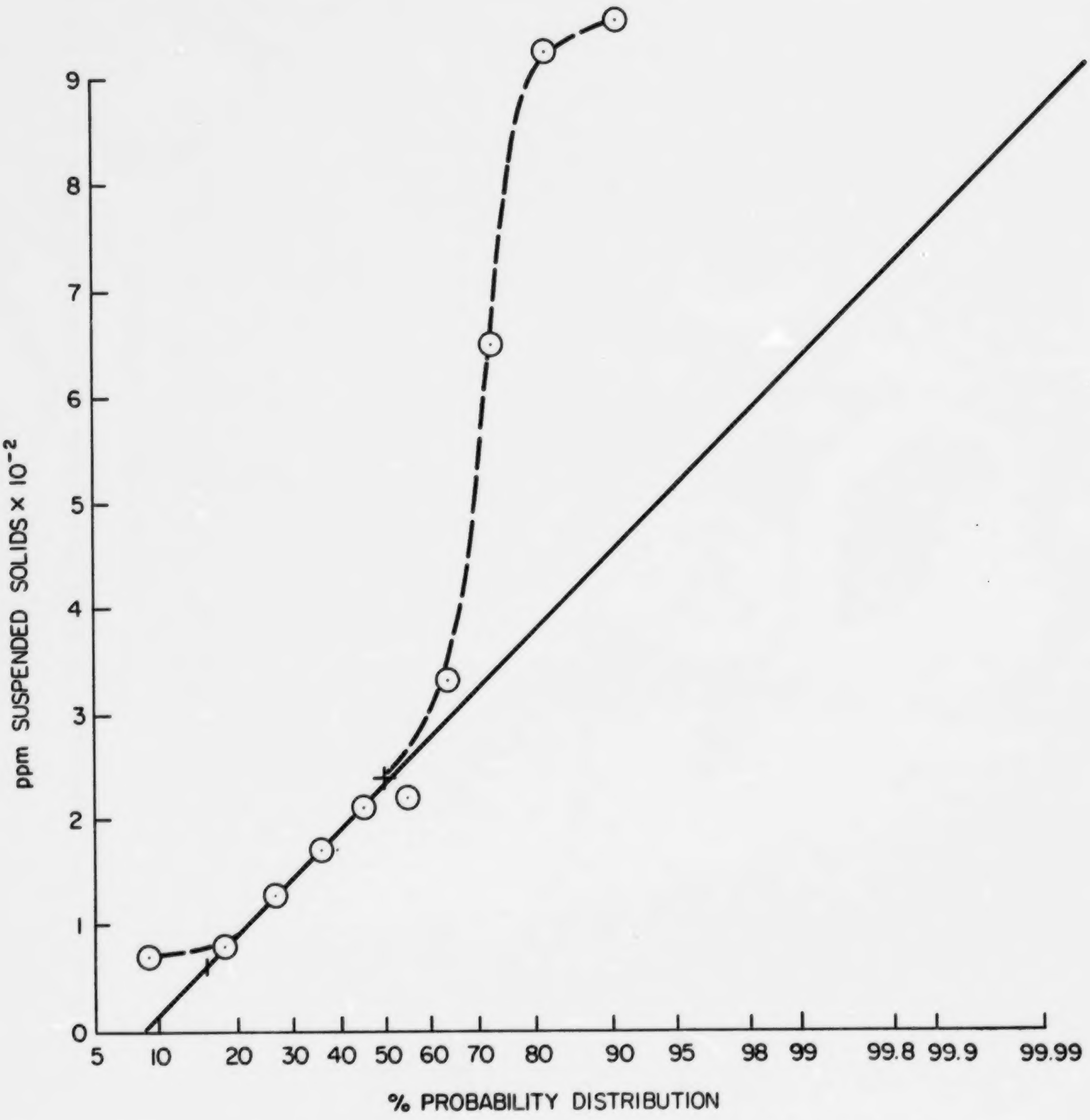


Figure 22 - Daily variation in suspended solids in waste water from dairy food plant E

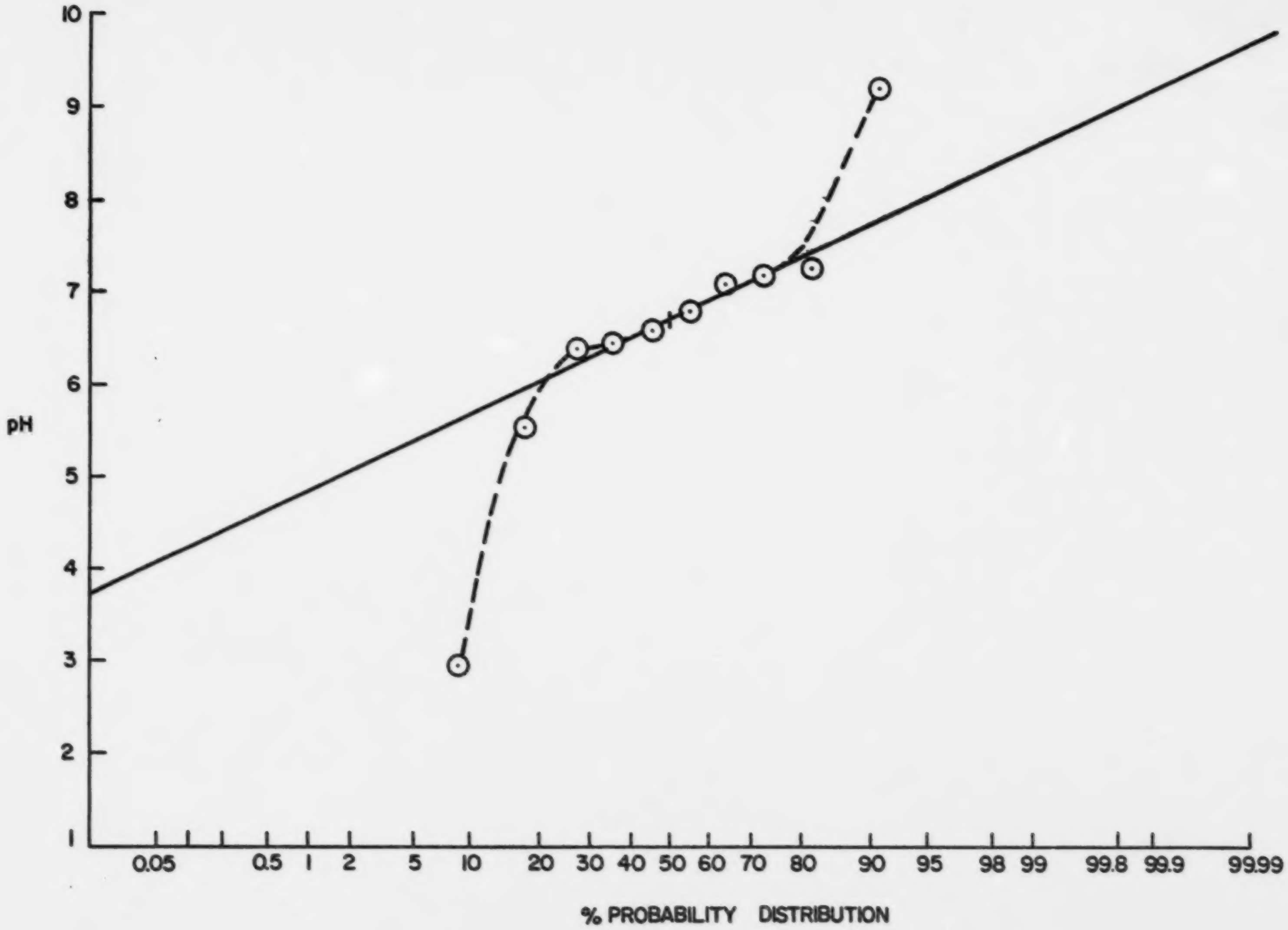


Figure 23 - Daily variation in pH of waste water from dairy food plant E

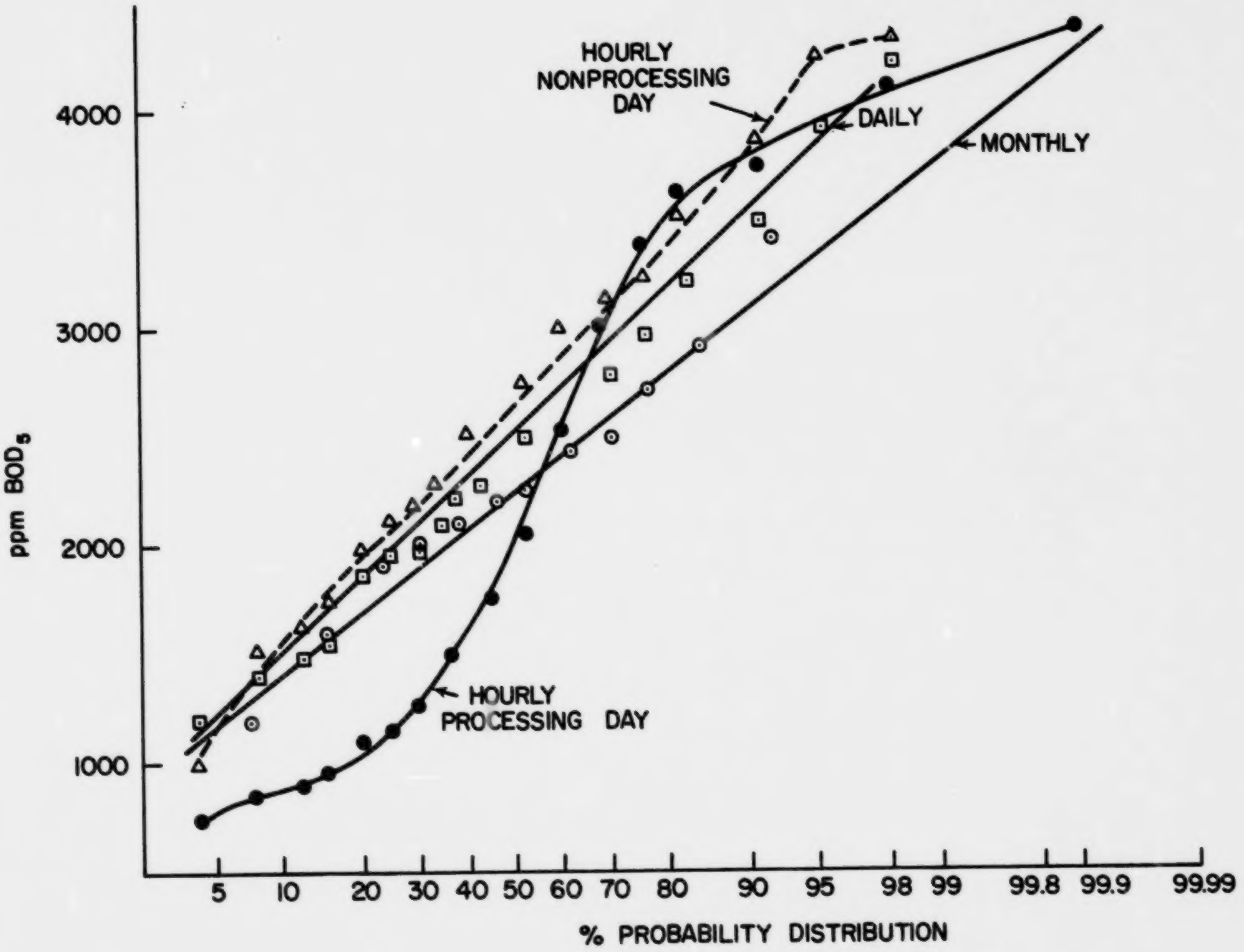


Figure 24 - Comparison of hourly, daily and monthly variability in BOD from waste water from dairy food plant B

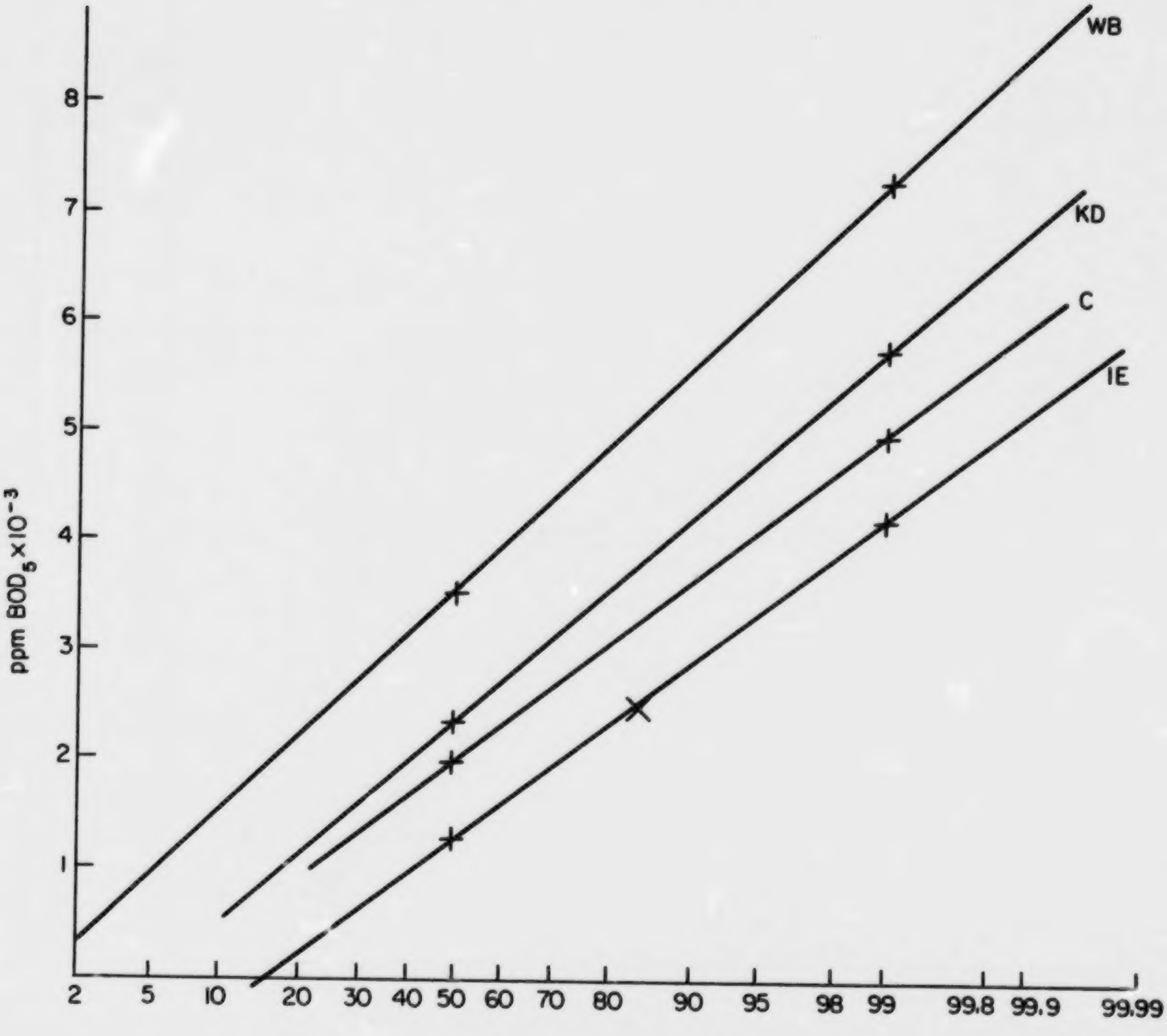


Figure 25 - Comparison of variability of BOD$_5$ values (monthly averages) in waste waters from different commercial dairy food plants

Variations can be expected to change with changing plant conditions. Figure 26 is a plot for plant B showing a change from 1969 to 1970, both in mean BOD and in the degree of variance. This variance could be related to a change in volume of production, a change in the work week and a change in management efficiency. Similar data are shown for plant G in Figure 27. This plant is an automated, modern operation, manufacturing ice cream, cottage cheese, market milk and related products. The plant was opened in 1965 and expanded its ice cream and cottage cheese operations during the next five years, as shown in Table 45. The waste water volume coefficient, ppm BOD and pounds of BOD have increased substantially since 1965. At the same time, the extent of variance has also increased.

Variation is a characteristic of dairy food plant wastes, which needs to be evaluated on a plant-to-plant basis, in order to provide information for both design and proper operation of waste treatment systems. On a daily basis, control of variables in the processes can result in a normal and predictable distribution of values around the mean. Generally, maximum values at a 1% confidence limit can be predicted by multiplying the mean value by 2.5. However, because of the individualist's nature of the values for waste volum, BOD_5, COD, temperature, pH, suspended solids and refractory chemicals, waste water should be assayed daily on a continuous sampling basis over a 30-day period to obtain reliable data for interpretation. All plants should be encouraged to install weirs, assay continuous samples, and evaluate waste waters on a daily basis as a part of the normal plant quality control program.

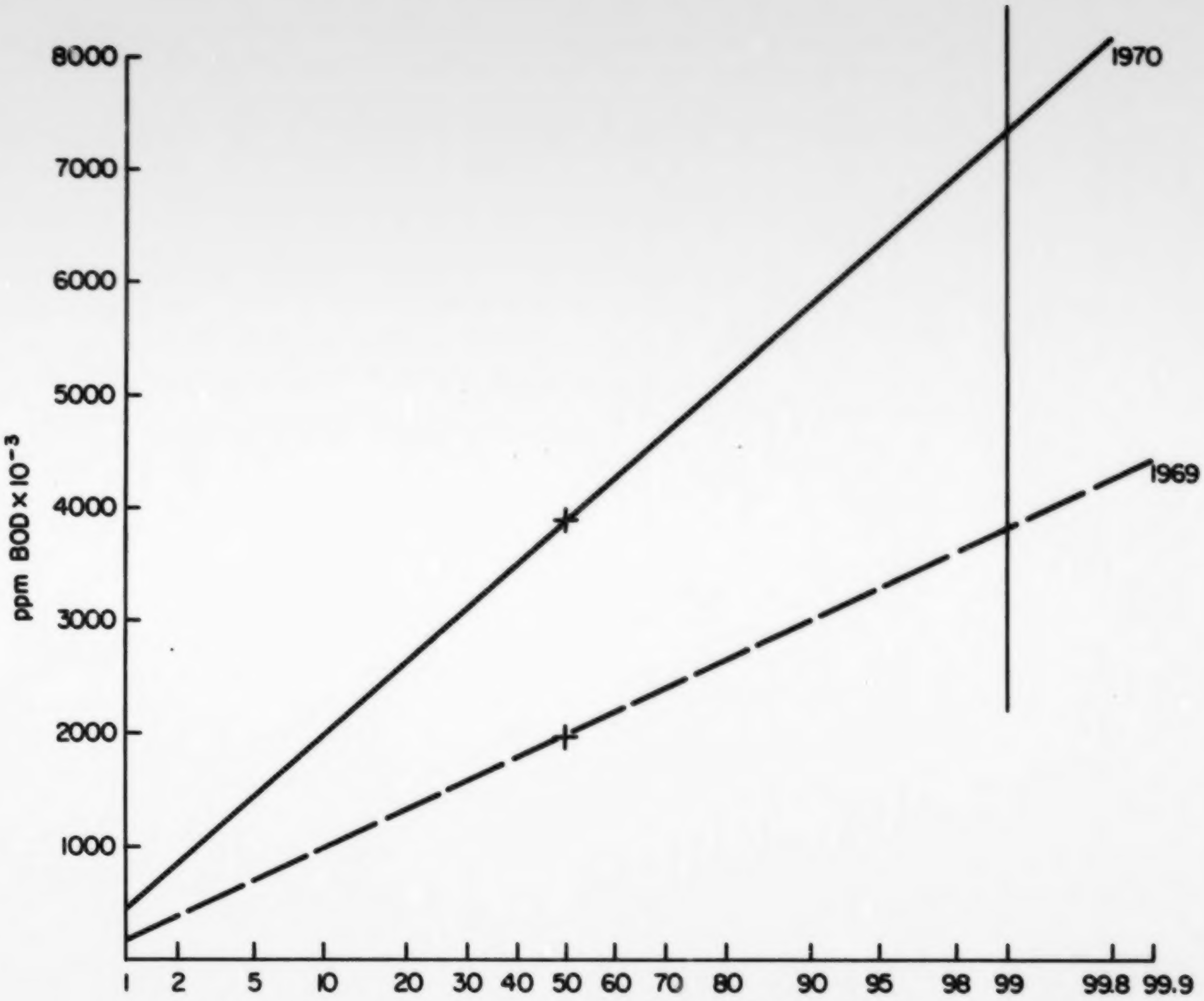


Figure 26 - Variability in monthly averages of BOD_5 values in waste water from plant B for two different years

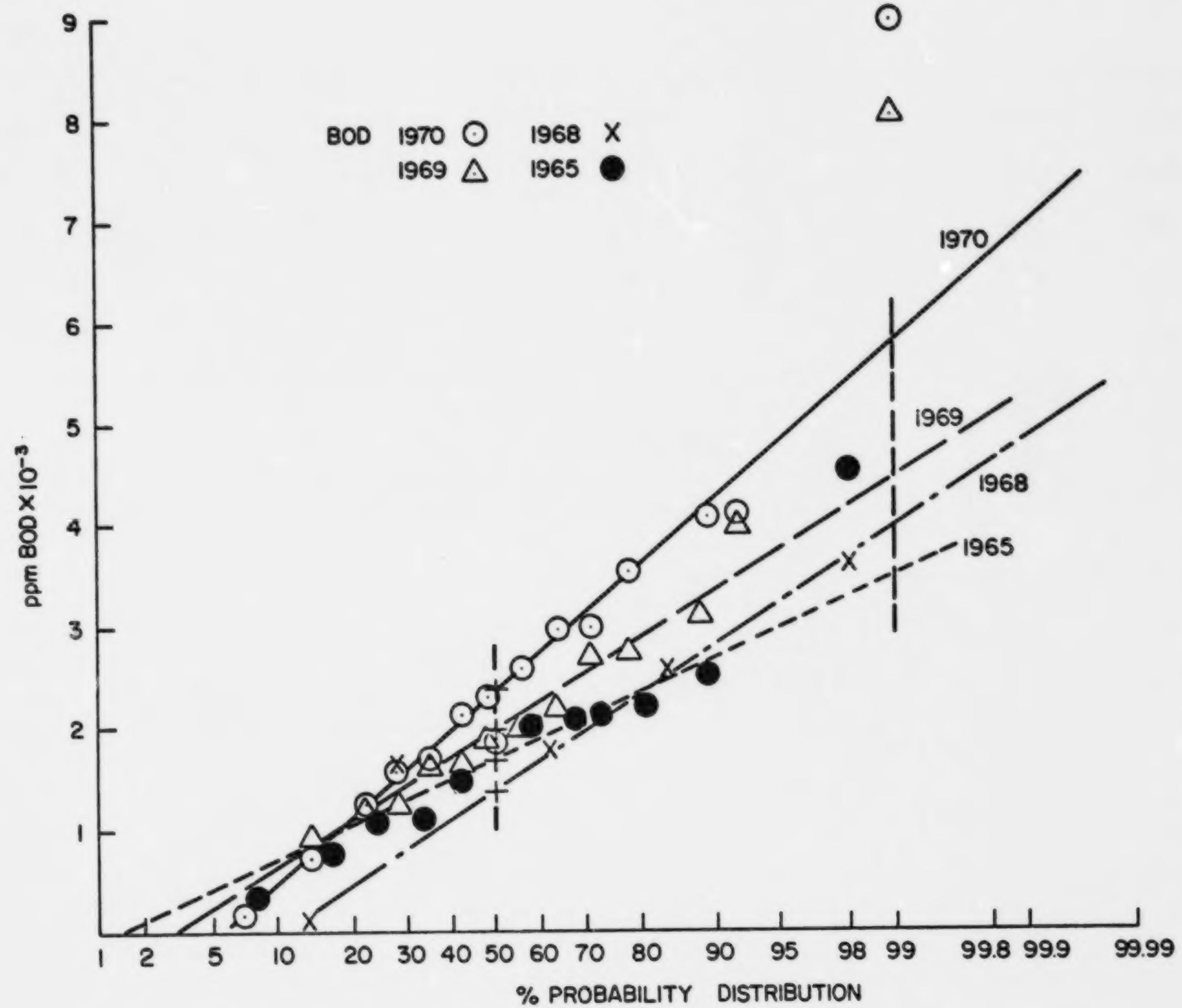


Figure 27 - Variability in monthly averages of BOD_5 in waste water from dairy food plant G for four different years

Table 45 - Changes in Production and Waste Loads Over a Five Year Period for Dairy Food Plant (G)

Year	Percent Product Mfg.			Percent Increase in Production			Waste Water
	Milk	Cottage Cheese	Ice Cream	Milk	Cottage Cheese	Ice Cream	Mil. Pound/Week
1965	86.2	0	13.8	--	--	--	11.76
1967	84.4	3.8	14.7	14.8	0	+25.0	14.2
1968	79.7	3.5	17.8	- 3.5	0	+30.0	18.4
1969	80.0	3.5	17.5	+14.6	+7.7	+16.6	19.6
1970	76.5	4.0	19.4	+ 6.4	+21.4	+14.3	20.2

Total Processed Mil. Pound/Week	Pound Waste Water/ Pound Milk Processed	Pound BOD/ 1000 Pound Milk Processed	ppm BOD		
			Av. BOD	1% Conf. Limit BOD	5% Conf. Limit BOD
2.9	4.1	7.0	1650	3500	3000
3.4	4.2	11.2	2309	3200	2800
3.7	4.9	13.2	2668	4000	3350
4.0	4.9	12.2	2550	4500	3750
4.2	4.8	13.4	2790	5800	4900

SECTION V

SOURCES OF DAIRY FOOD PLANT WASTES

Flow Sheets for Various Dairy Food Plant Operations

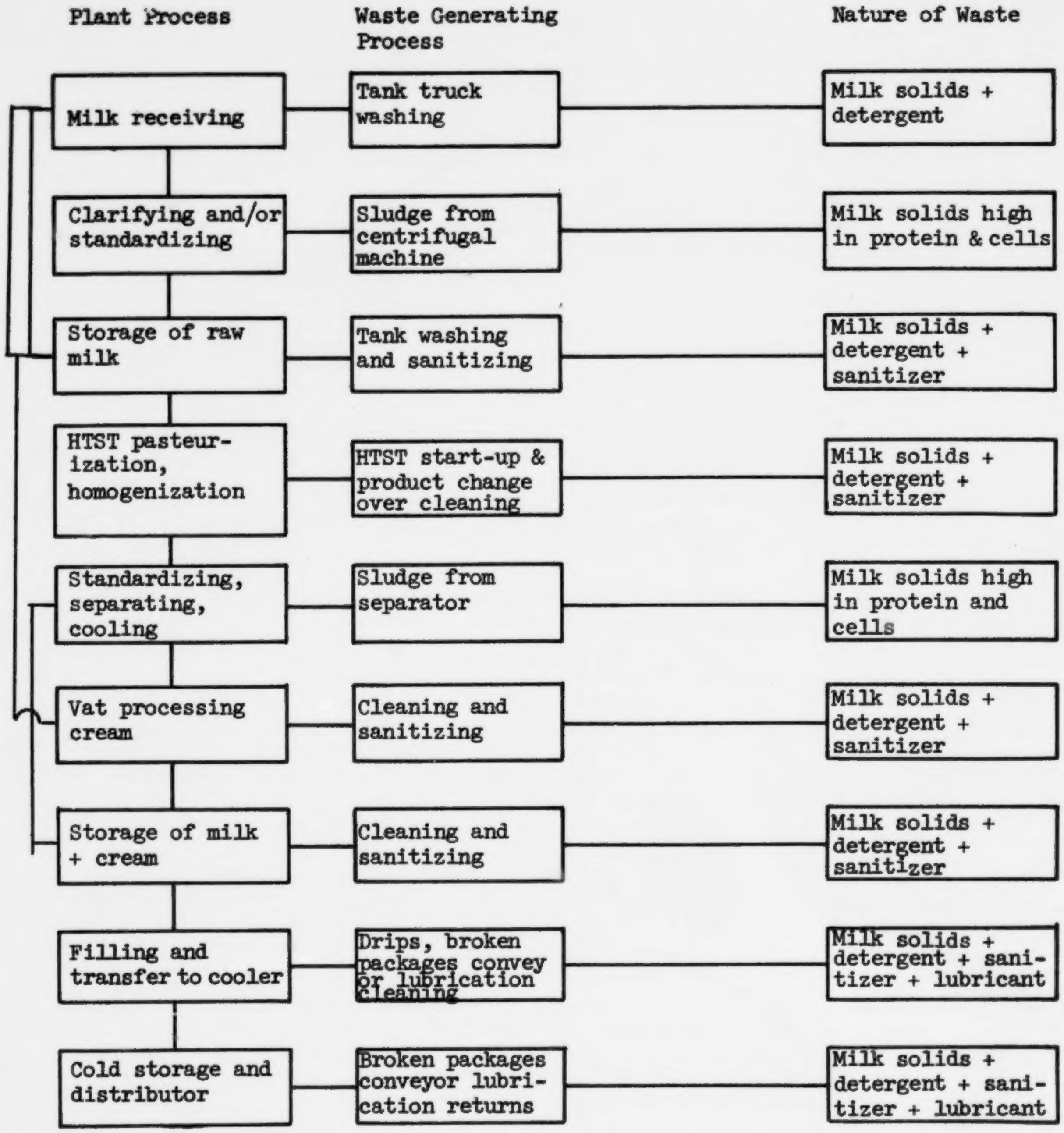
Determination of the significant sources of dairy food plant wastes requires an understanding of the processing of dairy foods, the various unit operations and their potential role as sources of waste water, milk solids and refractory compounds. Flow diagrams of various unit processes for processing milk into its various products, waste generation processes and the general nature of the waste for each type of unit operation is represented in Flow Diagrams 1-16. The waste generating processes of major significance include:

- washing, cleaning and sanitizing of all pipe lines, pumps, processing equipment, tanks, tank trucks and filling machines,
- start-up, product change over and shut down of HTST and UHT pasteurizers,
- loss in filling operations through equipment jams and broken packages,
- lubrication of casers, stackers and conveyors.

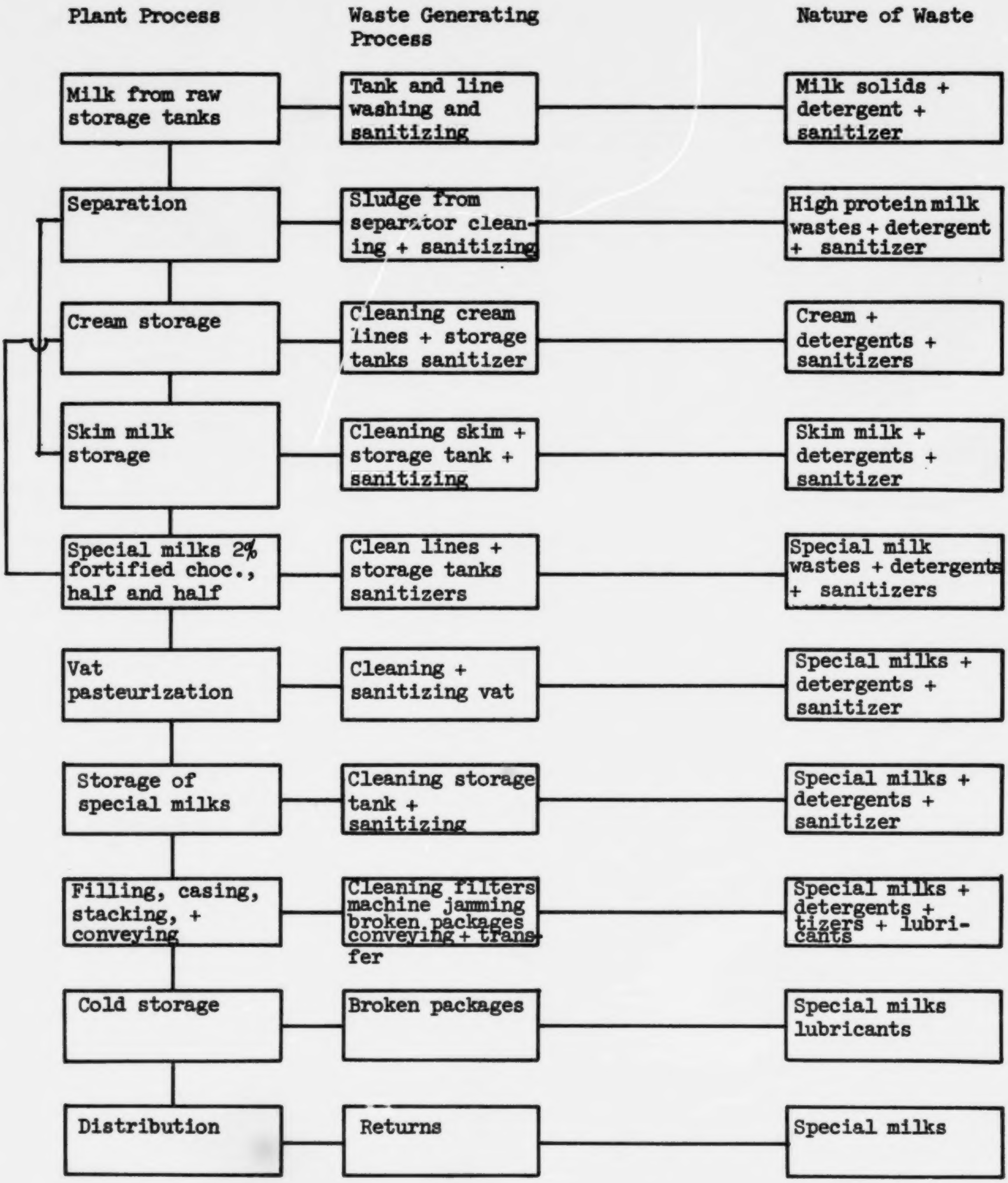
In the flow diagrams, the piping associated with a unit process is considered to be an integral part of that operation. Thus, the waste generating process of tank truck washing would include all pumps and piping in the receiving room; cleaning of raw storage tanks would include the associated raw milk pumps, valves and lines.

Spills and leaks from pipe-line joints, valves and pumps have not been included as waste generating processes in any of the flow diagrams. Although these sources are significant to varying degrees in different dairy food plants, they are inherently controllable through the application of good management practices. Generally the nature of the wastes generated by the various processes are similar; including milk solids in some form, plus detergents and sanitizers in most product processing steps and these same materials plus lubricants are generated in packaging and distribution operations. The significance of various waste generating processes to the total waste load of the dairy food plant waste water is a characteristic of the individual process and will be discussed in a later section of this report.

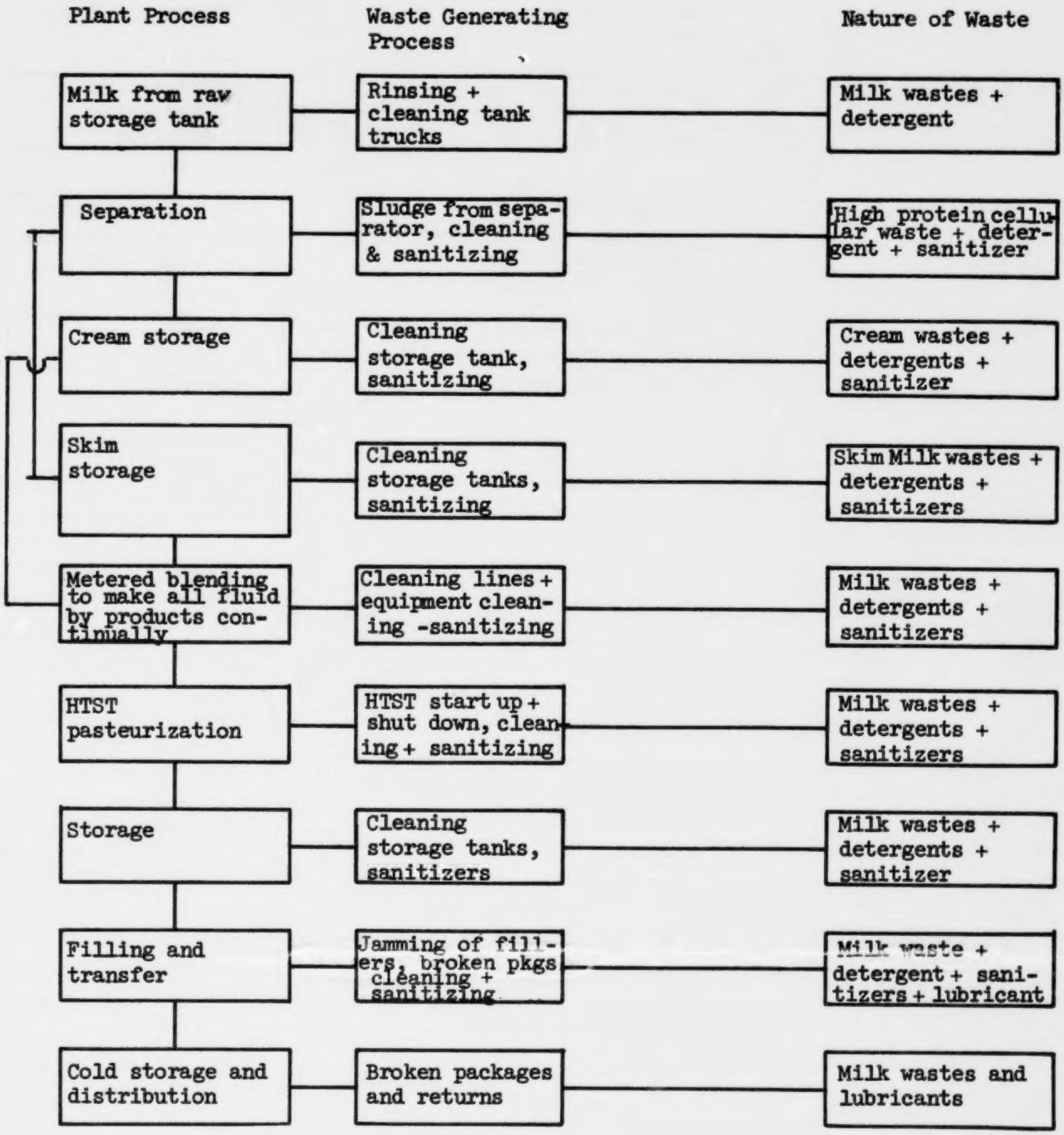
Fluid Milk Operations: Flow diagrams 1-5 are for fluid milk operations, their subprocesses and various alternative processes for certain by-products. Milk receiving and storage are common to all of the unit


Plant Process
Waste Generating Process
Nature of Waste
Milk receiving
Tank truck washing
Milk solids + detergent
Clarifying and/or standardizing
Sludge from centrifugal machine
Milk solids high in protein & cells
Storage of raw milk
Tank washing and sanitizing
Milk solids + detergent + sanitizer
HTST pasteurization, homogenization
HTST start-up & product change over cleaning
Milk solids + detergent + sanitizer
Standardizing, separating, cooling
Sludge from separator
Milk solids high in protein and cells
Vat processing cream
Cleaning and sanitizing
Milk solids + detergent + sanitizer
Storage of milk + cream
Cleaning and sanitizing
Milk solids + detergent + sanitizer
Filling and transfer to cooler
Drips, broken packages conveyor lubrication cleaning
Milk solids + detergent + sanitizer + lubricant
Cold storage and distributor
Broken packages conveyor lubrication returns
Milk solids + detergent + sanitizer + lubricant

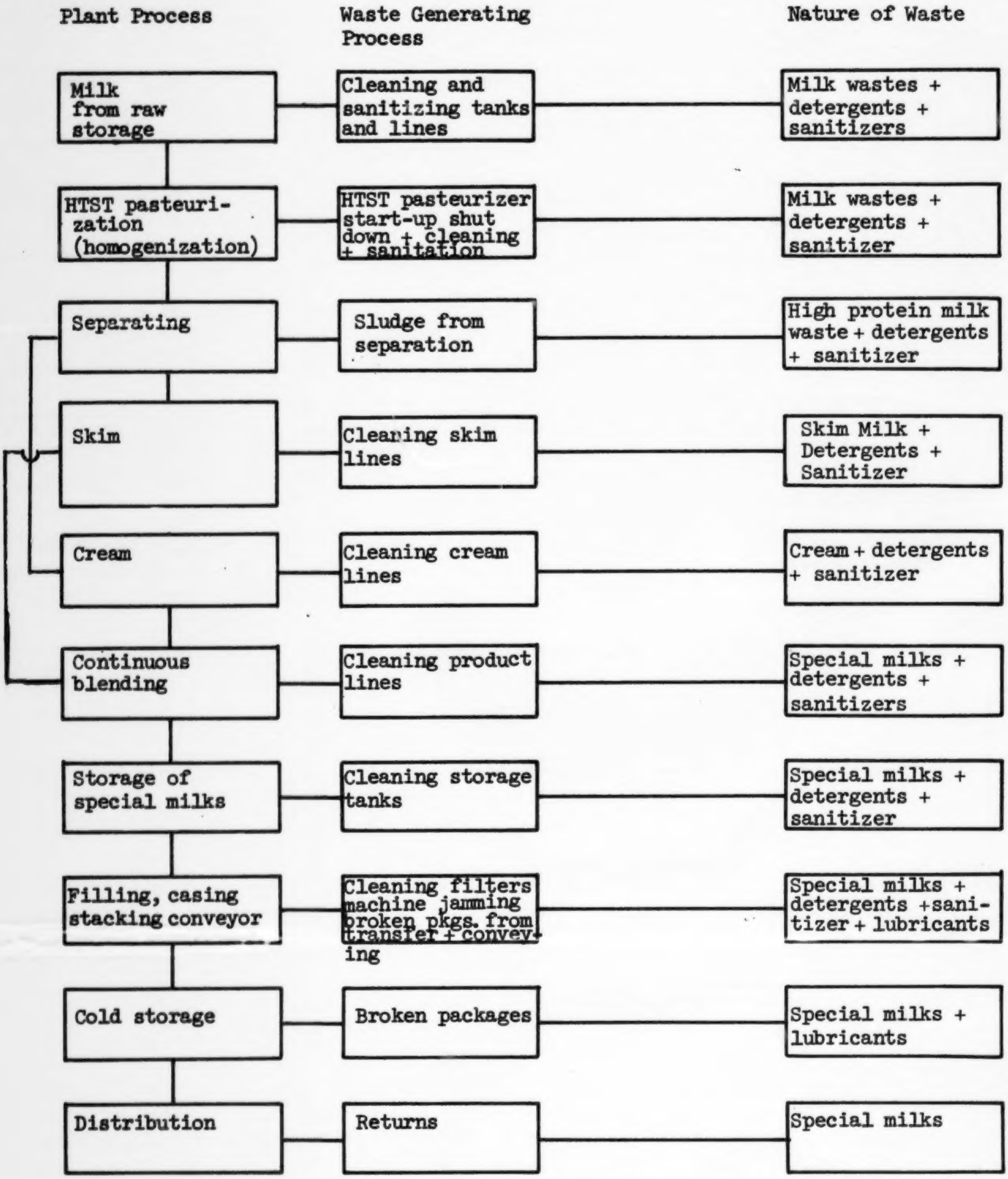
Flow Diagram 1 - Market Milk


Plant Process
Waste Generating Process
Nature of Waste
Milk from raw storage tanks
Tank and line washing and sanitizing
Milk solids + detergent + sanitizer
Separation
Sludge from separator cleaning + sanitizing
High protein milk wastes + detergent + sanitizer
Cream storage
Cleaning cream lines + storage tanks sanitizer
Cream + detergents + sanitizers
Skim milk storage
Cleaning skim + storage tank + sanitizing
Skim milk + detergents + sanitizer
Special milks 2% fortified choc., half and half
Clean lines + storage tanks sanitizers
Special milk wastes + detergents + sanitizers
Vat pasteurization
Cleaning + sanitizing vat
Special milks + detergents + sanitizer
Storage of special milks
Cleaning storage tank + sanitizing
Special milks + detergents + sanitizer
Filling, casing, stacking, + conveying
Cleaning filters machine jamming broken packages conveying + transfer
Special milks + detergents + tizers + lubricants
Cold storage
Broken packages
Special milks lubricants
Distribution
Returns
Special milks

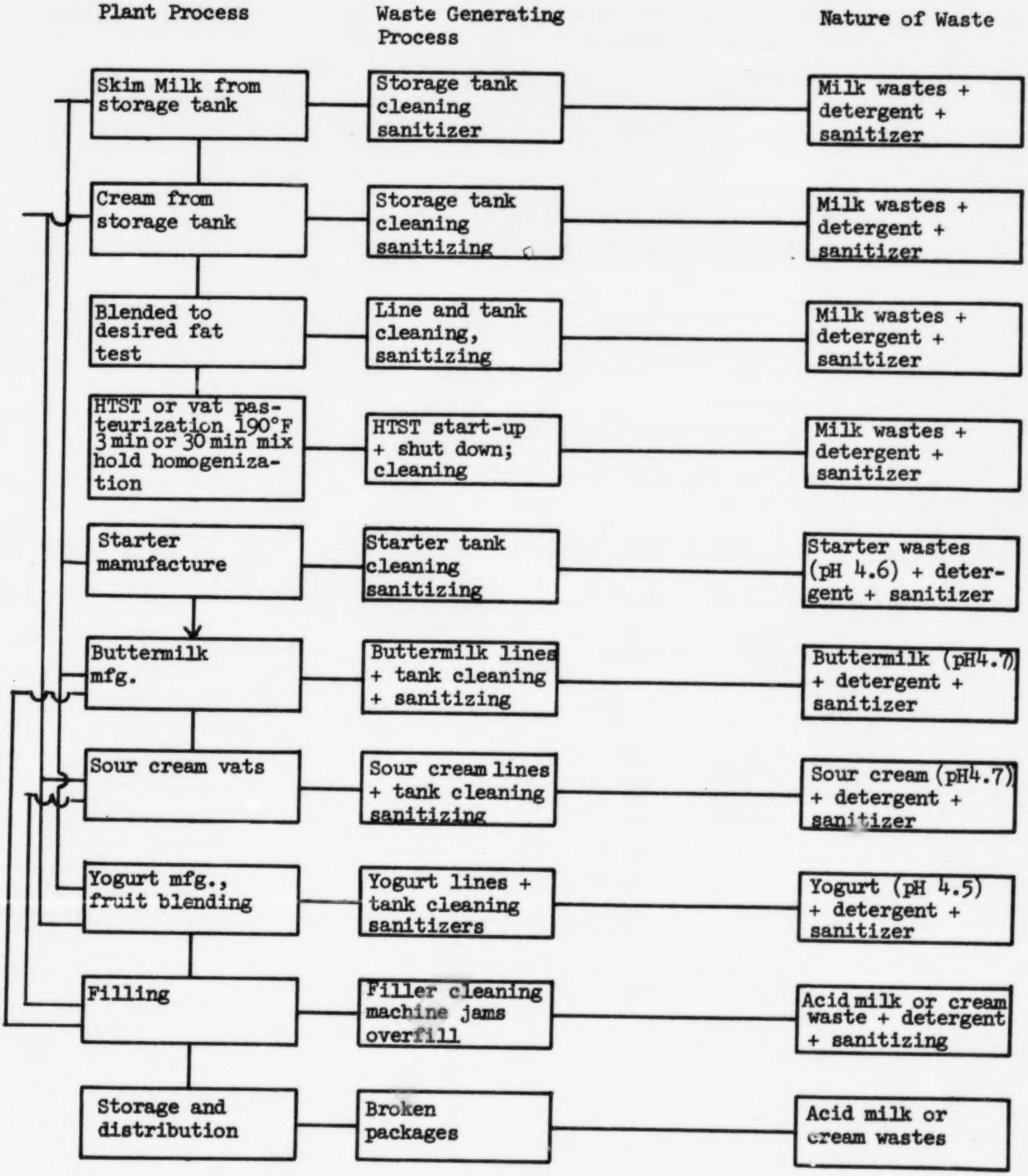
Flow Diagram 2 - Market Milk-Subprocess-Skim Milk, Creams and Special Milks by Batch Processing-Alternate 1


Plant Process
Waste Generating Process
Nature of Waste
Milk from raw storage tank
Rinsing + cleaning tank trucks
Milk wastes + detergent
Separation
Sludge from separator, cleaning & sanitizing
High protein cellular waste + detergent + sanitizer
Cream storage
Cleaning storage tank, sanitizing
Cream wastes + detergents + sanitizer
Skim storage
Cleaning storage tanks, sanitizing
Skim Milk wastes + detergents + sanitizers
Metered blending to make all fluid by products continually
Cleaning lines + equipment cleaning -sanitizing
Milk wastes + detergents + sanitizers
HTST pasteurization
HTST start up + shut down, cleaning + sanitizing
Milk wastes + detergents + sanitizers
Storage
Cleaning storage tanks, sanitizers
Milk wastes + detergents + sanitizer
Filling and transfer
Jamming of fillers, broken pkgs cleaning + sanitizing
Milk waste + detergent + sanitizers + lubricant
Cold storage and distribution
Broken packages and returns
Milk wastes and lubricants

Flow Diagram 3 - Market Milk-Subprocess-Skim Milk-Creams and Special Milks by Continuous Process-Alternate 2


Plant Process
Waste Generating Process
Nature of Waste
Milk from raw storage
Cleaning and sanitizing tanks and lines
Milk wastes + detergents + sanitizers
HTST pasteurization (homogenization)
HTST pasteurizer start-up shut down + cleaning + sanitation
Milk wastes + detergents + sanitizer
Separating
Sludge from separation
High protein milk waste + detergents + sanitizer
Skim
Cleaning skim lines
Skim Milk + Detergents + Sanitizer
Cream
Cleaning cream lines
Cream + detergents + sanitizer
Continuous blending
Cleaning product lines
Special milks + detergents + sanitizers
Storage of special milks
Cleaning storage tanks
Special milks + detergents + sanitizer
Filling, casing stacking conveyor
Cleaning filters machine jamming broken pkgs. from transfer + conveying
Special milks + detergents + sanitizer + lubricants
Cold storage
Broken packages
Special milks + lubricants
Distribution
Returns
Special milks

Flow Diagram 4 - Market Milk-Subprocess-Skim Milk-Creams and Special Milks by Continuous Process-Alternate 2


Plant Process
Waste Generating Process
Nature of Waste
Skim Milk from storage tank
Storage tank cleaning sanitizer
Milk wastes + detergent + sanitizer
Cream from storage tank
Storage tank cleaning sanitizing
Milk wastes + detergent + sanitizer
Blended to desired fat test
Line and tank cleaning, sanitizing
Milk wastes + detergent + sanitizer
HTST or vat pasteurization 190°F 3 min or 30 min mix hold homogenization
HTST start-up + shut down; cleaning
Milk wastes + detergent + sanitizer
Starter manufacture
Starter tank cleaning sanitizing
Starter wastes (pH 4.6) + detergent + sanitizer
Buttermilk mfg.
Buttermilk lines + tank cleaning + sanitizing
Buttermilk (pH4.7) + detergent + sanitizer
Sour cream vats
Sour cream lines + tank cleaning sanitizing
Sour cream (pH4.7) + detergent + sanitizer
Yogurt mfg., fruit blending
Yogurt lines + tank cleaning sanitizers
Yogurt (pH 4.5) + detergent + sanitizer
Filling
Filler cleaning machine jams overfill
Acid milk or cream waste + detergent + sanitizing
Storage and distribution
Broken packages
Acid milk or cream wastes

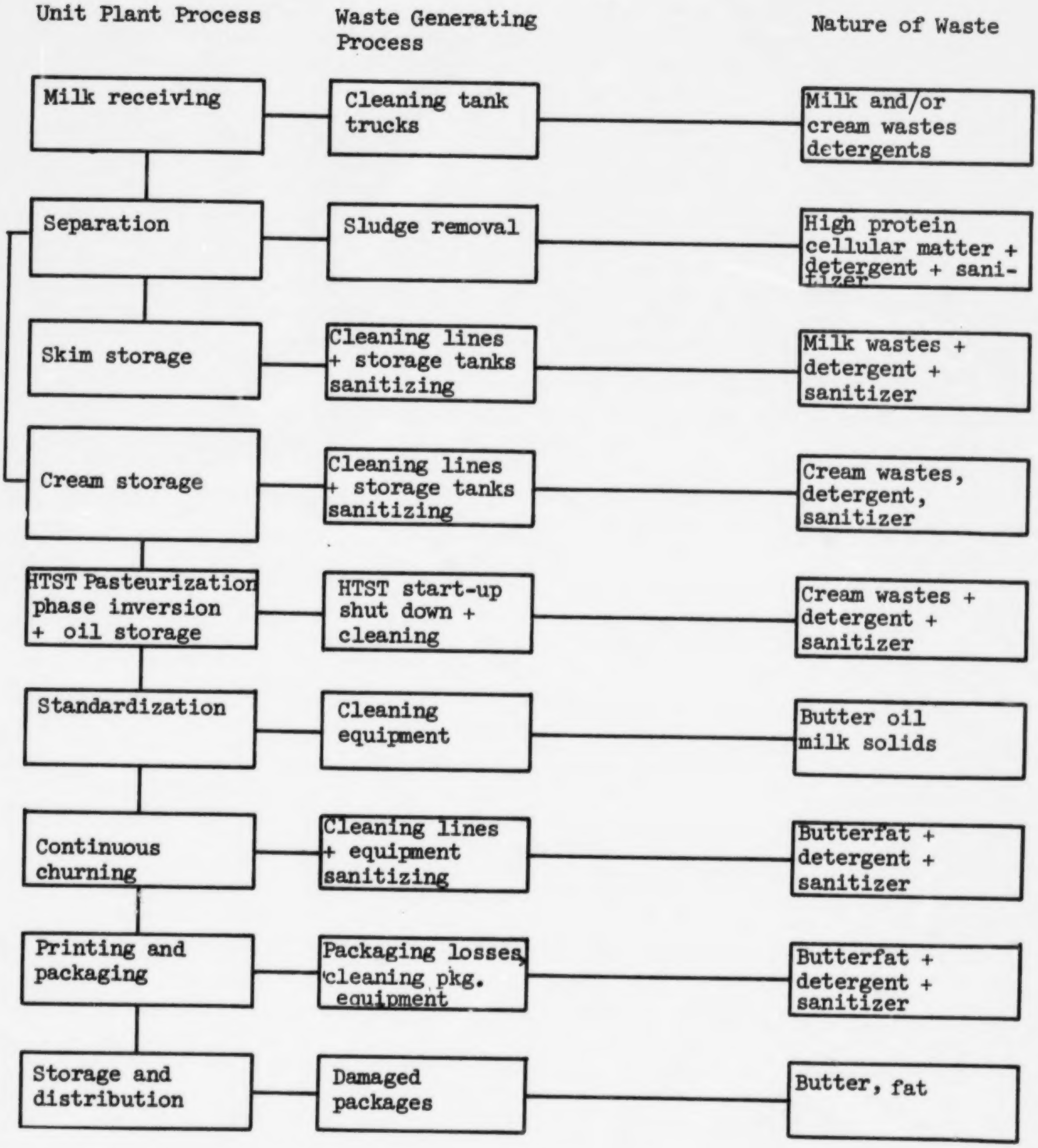
Flow Diagram 5 - Market Milk-Subprocesses: Buttermilk, and Yogurt Sour Cream operations and their subprocesses. Therefore, waste volume for BOD coefficients prepared for receiving and storage operations apply equally to all fluid milk processes and subprocesses, and apply also to other dairy food plants receiving milk by tank truck. Other unit operations that apply to all dairy food plants include the utilization of centrifugal machines, (for clarifying, separating and/or standardizing) pasteurized product, and filling and distribution). In market milk processing the significant waste generating processes include tank washing, sludge centrifugal machines, tank washing and sanitizing, high-temperature short-time start-up and product change over, cleaning high temperature short-time period cleaning and sanitizing of processing vats and lines, cleaning and sanitizing of storage vats, drips, broken packages, damaged packages, cleaning of fillers, conveyor lubrication and cleaning; broken packages, conveyor lubrication and returns constitute waste generated steps in cold storage and distribution.

Butter: Flow diagrams 6 and 7 give the outlines of the churn and the continuous method for butter operation. The continuous process materially reduces potential waste strength by eliminating the buttermilk production and the washing steps. Disposition of skimmilk and buttermilk for food use may be accomplished by the use of a drying operation in conjunction with the butter operation, or these materials may be shipped to another dairy food plant by tank truck.

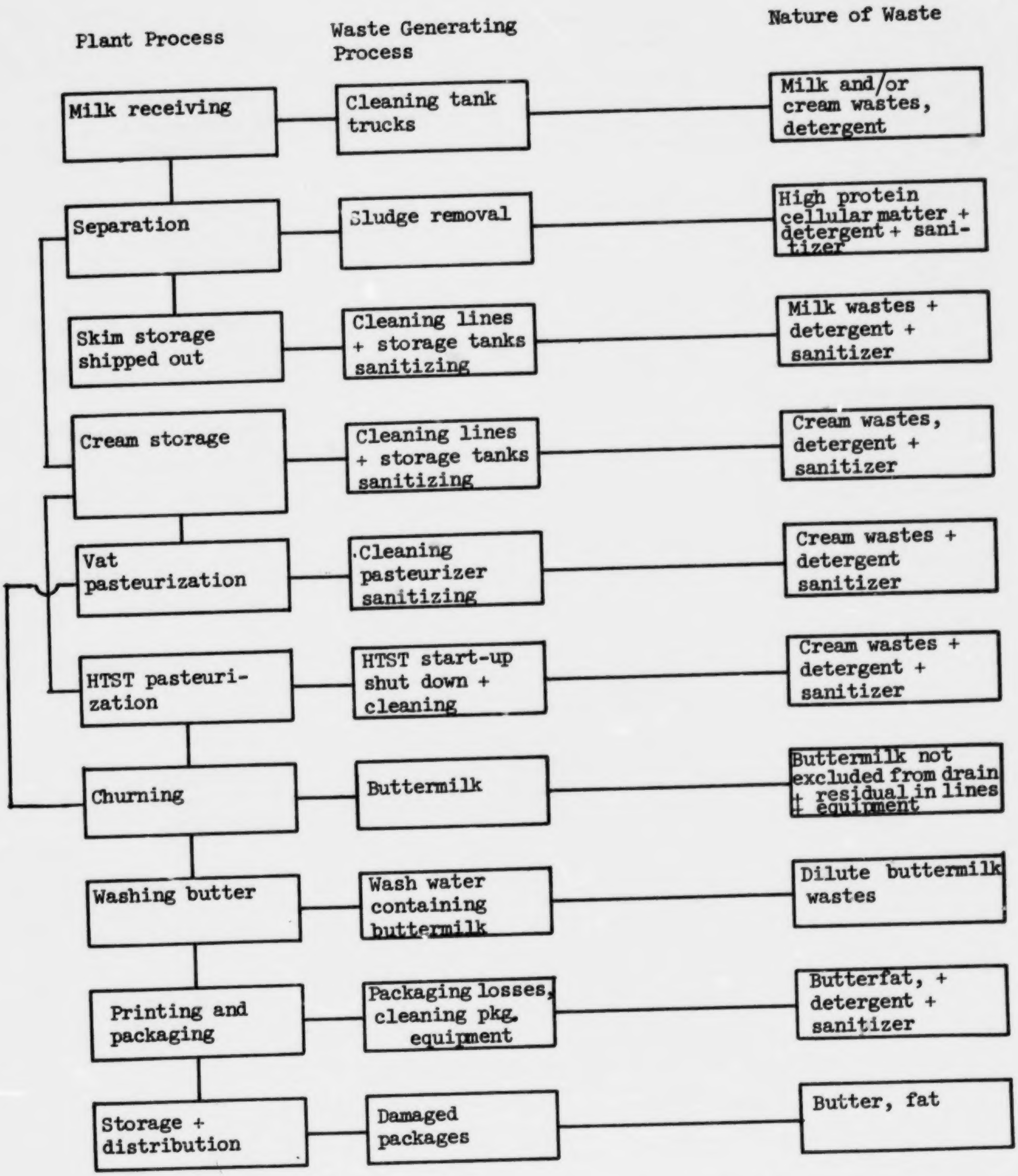
Cheese: Unit process operations, waste generating processes and the nature of wastes for cottage cheese, cheddar cheese, Swiss cheese and Italian cheese operations are outlined in Flow Diagrams 8-11 to represent different types of cheese manufacturing processes.

The most visible source of waste in the dairy industry is in the whey resulting from the various cheese operations. There has been an increasing trend in the industry to exclude all whey from waste treatment and to use it for feed or food. Where whey is to be shipped to another plant for processing into a concentrated form for food use, the cheese factory has had to install (or utilize) sanitary storage tanks and cooling equipment to prevent the outgrowth of food infectious or poisoning organisms prior to shipment. Washing and cleaning of such equipment would constitute another waste generating step not shown in the flow diagrams.

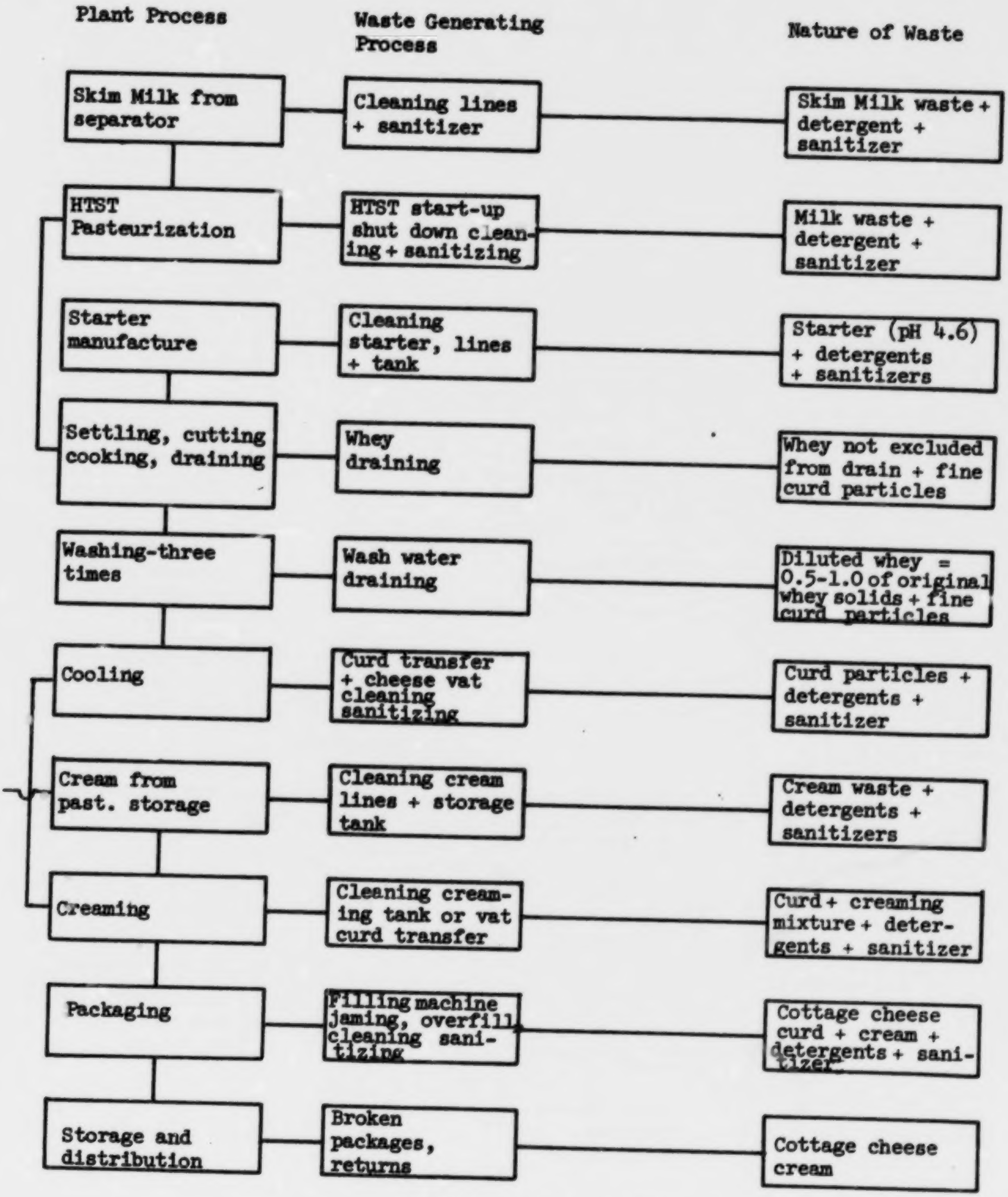
The cottage cheese operation differs from the other cheese processing in that it produces a whey of low pH (4.5-4.7) and utilizes wash water (equal to twice the whey volume) to remove residual whey, lactose and lactic acid from the curd. Cottage cheese curd is more fragile than rennet curd which is used for the other three types of cheese. Thus the whey and wash water may contain appreciable fine curd particles ("fines"). The amount of "fines" in the wash water is increased if mechanical washing (such as the "Curd-O-Matic") processes are used. Complete draining of the curd, a "pre-wash" of 5% of the whey volume with draining and a combination of this material with the whey to be sold for feed or food use or use of whey to cool the curd can decrease the BOD of the wash water by 20% to 40%.


Unit Plant Process
Waste Generating Process
Nature of Waste
Milk receiving
Cleaning tank trucks
Milk and/or cream wastes detergents
Separation
Sludge removal
High protein cellular matter + detergent + sanitizer
Skim storage
Cleaning lines + storage tanks sanitizing
Milk wastes + detergent + sanitizer
Cream storage
Cleaning lines + storage tanks sanitizing
Cream wastes, detergent, sanitizer
HTST Pasteurization phase inversion + oil storage
HTST start-up shut down + cleaning
Cream wastes + detergent + sanitizer
Standardization
Cleaning equipment
Butter oil milk solids
Continuous churning
Cleaning lines + equipment sanitizing
Butterfat + detergent + sanitizer
Printing and packaging
Packaging losses, cleaning pkg. equipment
Butterfat + detergent + sanitizer
Storage and distribution
Damaged packages
Butter, fat

Flow Diagram 6 - Butter-Continuous Process

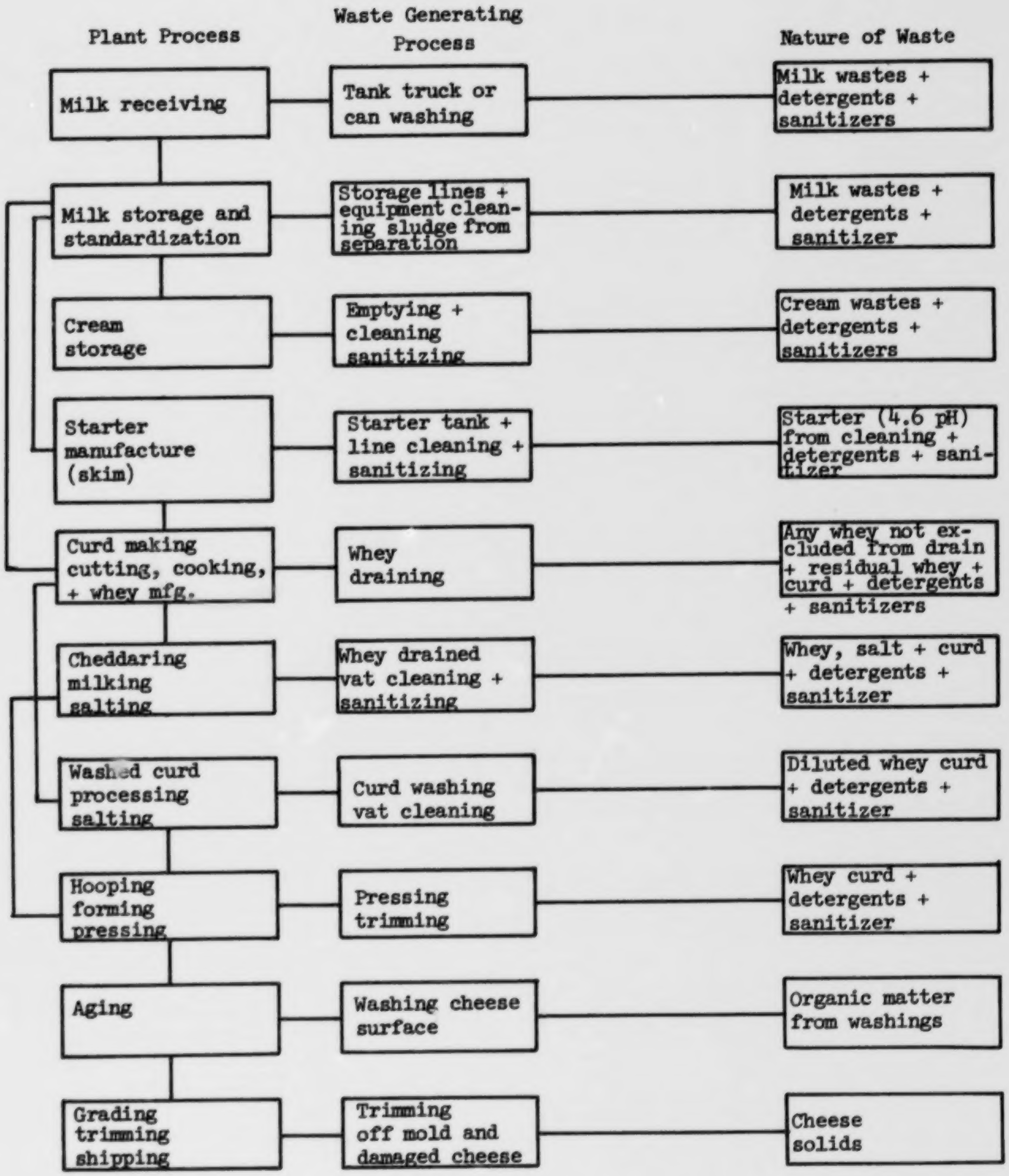

Plant Process
Waste Generating Process
Nature of Waste
Milk receiving
Cleaning tank trucks
Milk and/or cream wastes, detergent
Separation
Sludge removal
High protein cellular matter + detergent + sanitizer
Skim storage shipped out
Cleaning lines + storage tanks sanitizing
Milk wastes + detergent + sanitizer
Cream storage
Cleaning lines + storage tanks sanitizing
Cream wastes, detergent + sanitizer
Vat pasteurization
Cleaning pasteurizer sanitizing
Cream wastes + detergent sanitizer
HTST pasteurization
HTST start-up shut down + cleaning
Cream wastes + detergent + sanitizer
Churning
Buttermilk
Buttermilk not excluded from drain + residual in lines + equipment
Washing butter
Wash water containing buttermilk
Dilute buttermilk wastes
Printing and packaging
Packaging losses, cleaning pkg. equipment
Butterfat, + detergent + sanitizer
Storage + distribution
Damaged packages
Butter, fat

Flow Diagram 7 - Butter-Churn Process

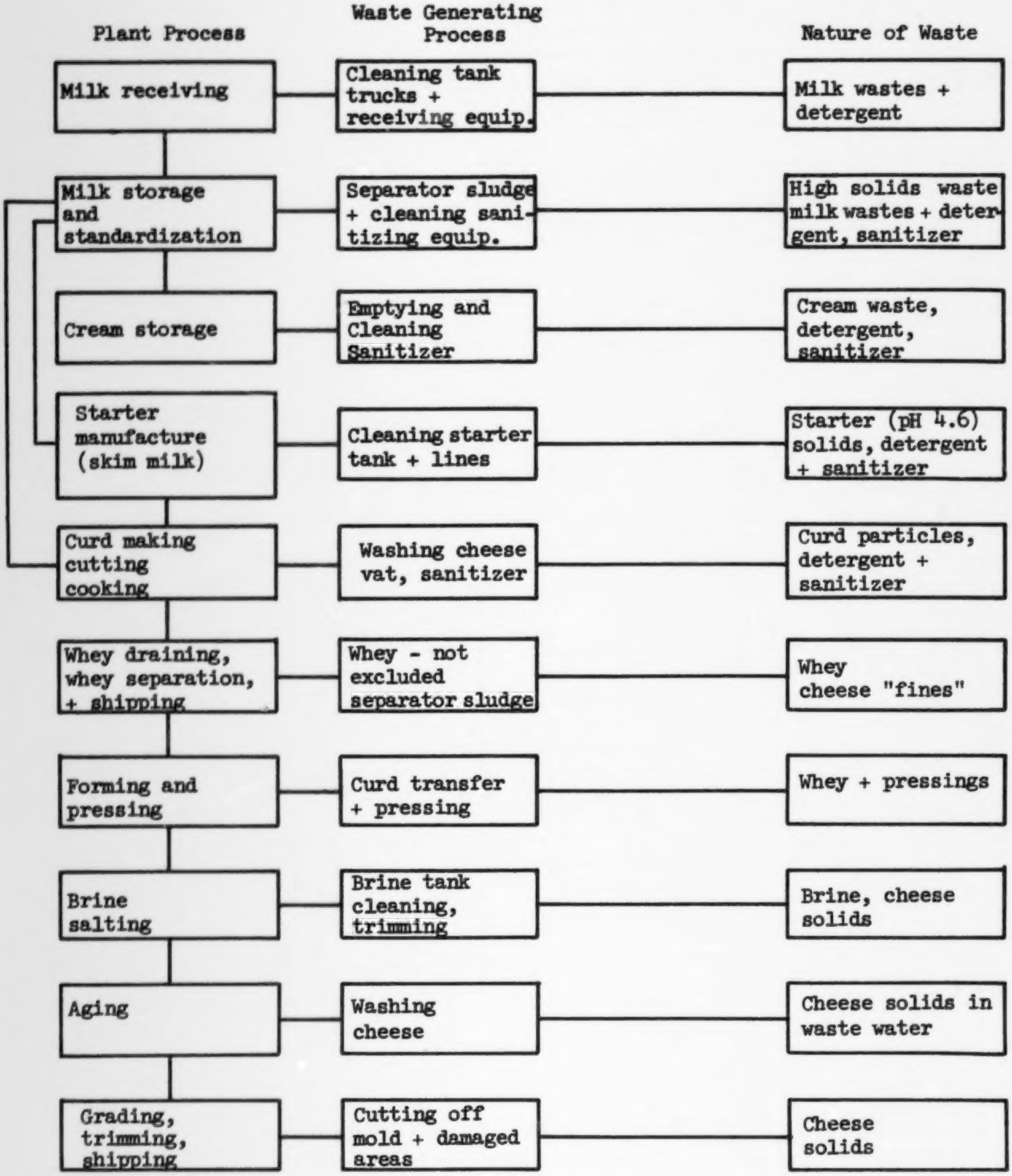


Plant Process	Waste Generating Process	Nature of Waste
Skim Milk from separator	Cleaning lines + sanitizer	Skim Milk waste + detergent + sanitizer
HTST Pasteurization	HTST start-up shut down cleaning + sanitizing	Milk waste + detergent + sanitizer
Starter manufacture	Cleaning starter, lines + tank	Starter (pH 4.6) + detergents + sanitizers
Settling, cutting cooking, draining	Whey draining	Whey not excluded from drain + fine curd particles
Washing-three times	Wash water draining	Diluted whey = 0.5-1.0 of original whey solids + fine curd particles
Cooling	Curd transfer + cheese vat cleaning sanitizing	Curd particles + detergents + sanitizer
Cream from past. storage	Cleaning cream lines + storage tank	Cream waste + detergents + sanitizers
Creaming	Cleaning creaming tank or vat curd transfer	Curd + creaming mixture + detergents + sanitizer
Packaging	Filling machine jaming, overfill, cleaning sanitizing	Cottage cheese curd + cream + detergents + sanitizer
Storage and distribution	Broken packages, returns	Cottage cheese cream

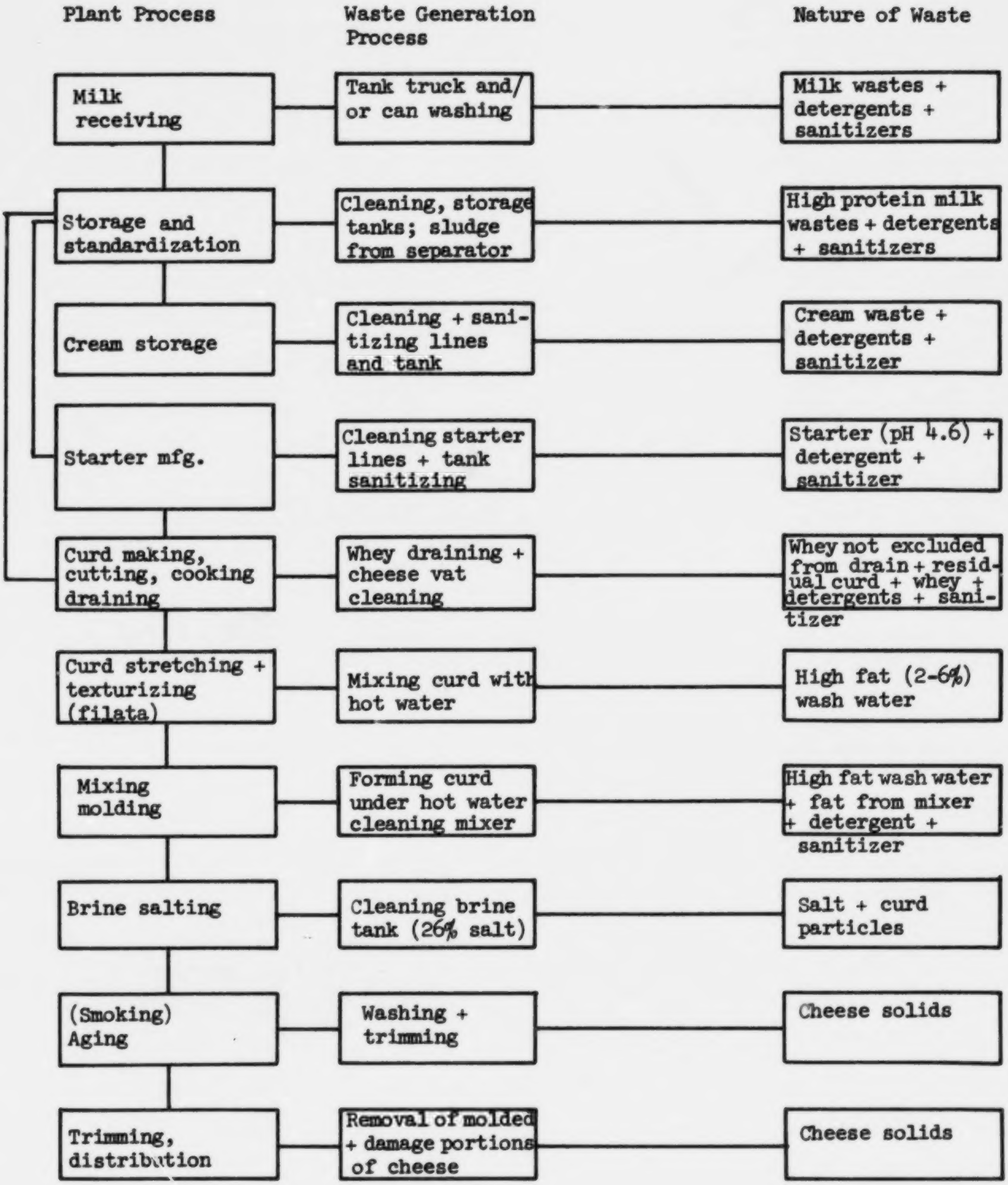
Flow Diagram 8 - Cottage Cheese


Plant Process
Waste Generating Process
Nature of Waste
Milk receiving
Tank truck or can washing
Milk wastes + detergents + sanitizers
Milk storage and standardization
Storage lines + equipment cleaning sludge from separation
Milk wastes + detergents + sanitizer
Cream storage
Emptying + cleaning sanitizing
Cream wastes + detergents + sanitizers
Starter manufacture (skim)
Starter tank + line cleaning + sanitizing
Starter (4.6 pH) from cleaning + detergents + sanitizer
Curd making cutting, cooking, + whey mfg.
Whey draining
Any whey not excluded from drain + residual whey + curd + detergents + sanitizers
Cheddaring milking salting
Whey drained vat cleaning + sanitizing
Whey, salt + curd + detergents + sanitizer
Washed curd processing salting
Curd washing vat cleaning
Diluted whey curd + detergents + sanitizer
Hooping forming pressing
Pressing trimming
Whey curd + detergents + sanitizer
Aging
Washing cheese surface
Organic matter from washings
Grading trimming shipping
Trimming off mold and damaged cheese
Cheese solids

Flow Diagram 9 - Cheddar Cheese Manufacture


Plant Process
Waste Generating Process
Nature of Waste
Milk receiving
Cleaning tank trucks + receiving equip.
Milk wastes + detergent
Milk storage and standardization
Separator sludge + cleaning sanitizing equip.
High solids waste milk wastes + detergent, sanitizer
Cream storage
Emptying and Cleaning Sanitizer
Cream waste, detergent, sanitizer
Starter manufacture (skim milk)
Cleaning starter tank + lines
Starter (pH 4.6) solids, detergent + sanitizer
Curd making cutting cooking
Washing cheese vat, sanitizer
Curd particles, detergent + sanitizer
Whey draining, whey separation, + shipping
Whey - not excluded separator sludge
Whey cheese "fines"
Forming and pressing
Curd transfer + pressing
Whey + pressings
Brine salting
Brine tank cleaning, trimming
Brine, cheese solids
Aging
Washing cheese
Cheese solids in waste water
Grading, trimming, shipping
Cutting off mold + damaged areas
Cheese solids

Flow Diagram 10 - Swiss Cheese Manufacture


Plant Process
Waste Generation Process
Nature of Waste
Milk receiving
Tank truck and/ or can washing
Milk wastes + detergents + sanitizers
Storage and standardization
Cleaning, storage tanks; sludge from separator
High protein milk wastes + detergents + sanitizers
Cream storage
Cleaning + sanitizing lines and tank
Cream waste + detergents + sanitizer
Starter mfg.
Cleaning starter lines + tank sanitizing
Starter (pH 4.6) + detergent + sanitizer
Curd making, cutting, cooking draining
Whey draining + cheese vat cleaning
Whey not excluded from drain + residual curd + whey + detergents + sanitizer
Curd stretching + texturizing (filata)
Mixing curd with hot water
High fat (2-6%) wash water
Mixing molding
Forming curd under hot water cleaning mixer
High fat wash water + fat from mixer + detergent + sanitizer
Brine salting
Cleaning brine tank (26% salt)
Salt + curd particles
(Smoking) Aging
Washing + trimming
Cheese solids
Trimming, distribution
Removal of molded + damage portions of cheese
Cheese solids

Flow Diagram 11 - Cheese-Pasta Filata (Provolone, Mozzarella) Cheese Manufacture

In cheddar cheese, the whey draining during cheddaring (matting of the curd) and pressing should be collected and combined with the whey.

In Swiss cheese manufacture, appreciable whey is lost in the transfer of the curd (150-300 lb) from the vat to the draining table.

In Provodone and Mozzarella manufacture, the milling, mixing and molding of the curd produces a high fat, low pH (5.1-5.3) wash water from which 3 to 5% fat can be recovered by centrifugation.

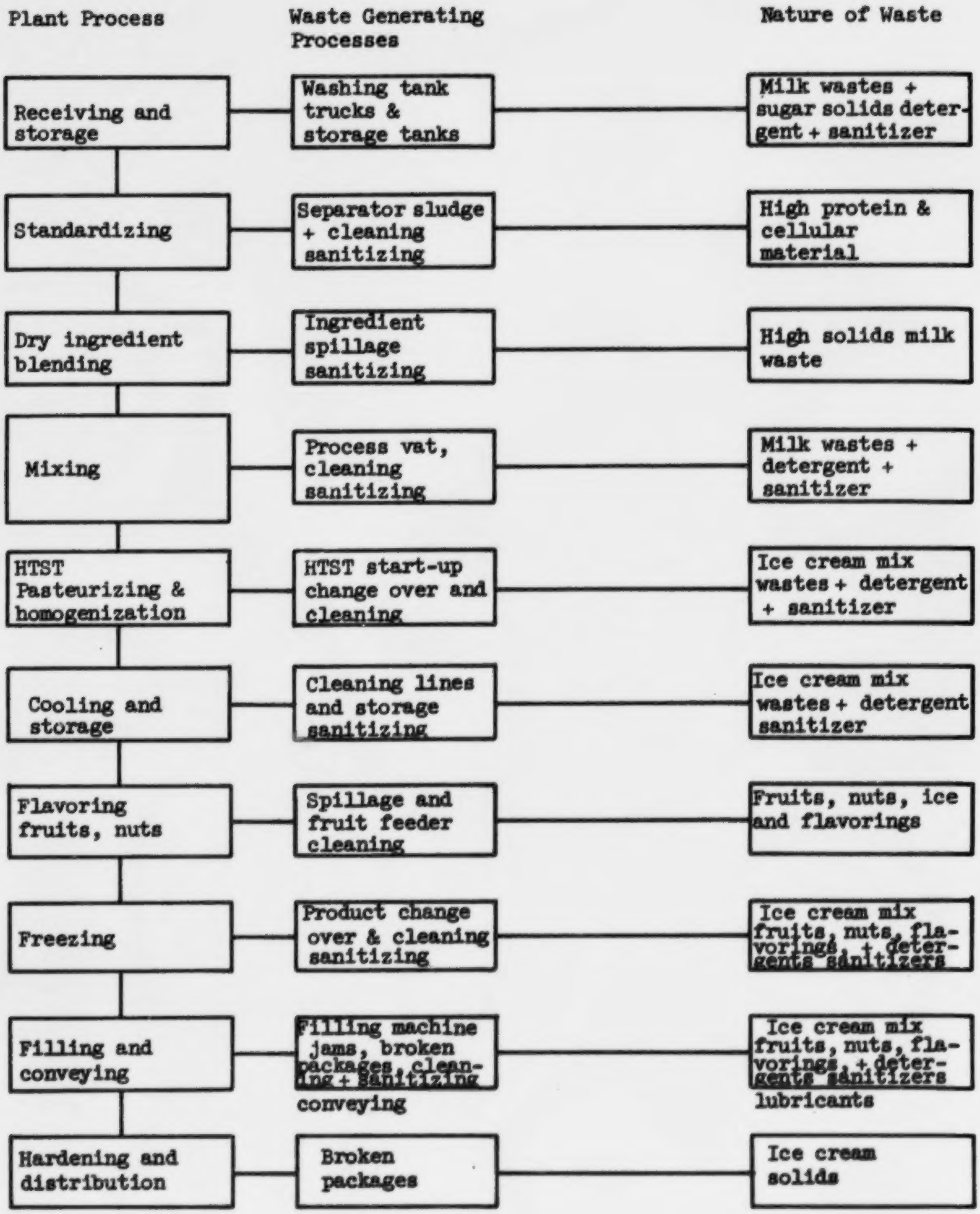
Ice Cream Operations: The unit operations and sources of wastes are indicated in Flow Diagrams 12-13 for ice cream, frozen dessert operations and subprocesses. Alternative pathways are illustrated for novelty preparations. Because of high viscosity and high BOD values, incomplete draining of ice cream and ice cream mix lines and equipment can be a major source of BOD and suspended solids (SS) (nuts, fruits, etc.) in dairy food plant waste water.

Waste Water Volume Coefficient for Various Plant Operations

Relatively little information is available concerning the amount of water per unit weight of milk processes as utilized in various types of dairy food plant operations (894, 980, 1206). Information available in the literature and that obtained from industry has been summarized and presented in Table 46. Major processes utilizing water are wash water for cottage cheese, cooling water, and condensing water. Cooling waters are generally free from waste and could be segregated from other operations to minimize hydraulic loading up to 70%.

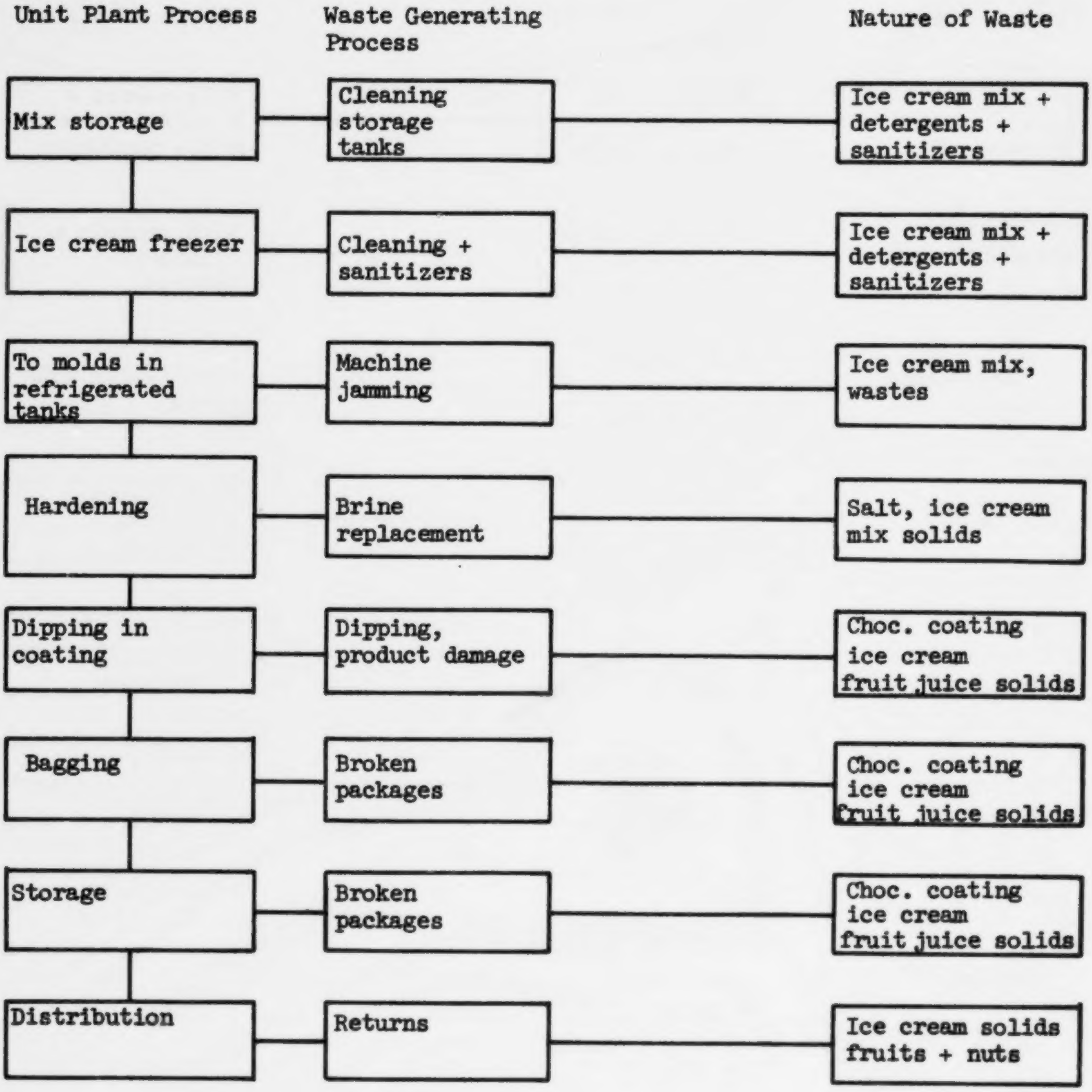
SOURCES OF BOD

Table 47 is the average reported BOD coefficients (pound BOD_5/1000 pounds of milk produced) for various fluid dairy plant operations reported in the literature. The earliest reported data were those of Trebler and Harding (1133) in 1947, which were revised in 1949, and subsequently revised by a dairy industry committee and published in the 1967 issue of Milk Industry Foundation Milk Plant Operators Manual. The Scottish Milk Market Board and Royal in England have also presented data on BOD coefficients. Although the values do not cover exactly the same unit operations, the coefficients for unit processes are in good agreement with the revised Trebler and Harding data and can be utilized to develop an indication of waste loads in different types of combination plants. It should be emphasized that, whereas whey is the most visible BOD source (260 pound BOD/1000 pound milk processed), other dairy food plant operations are significant sources of BOD.



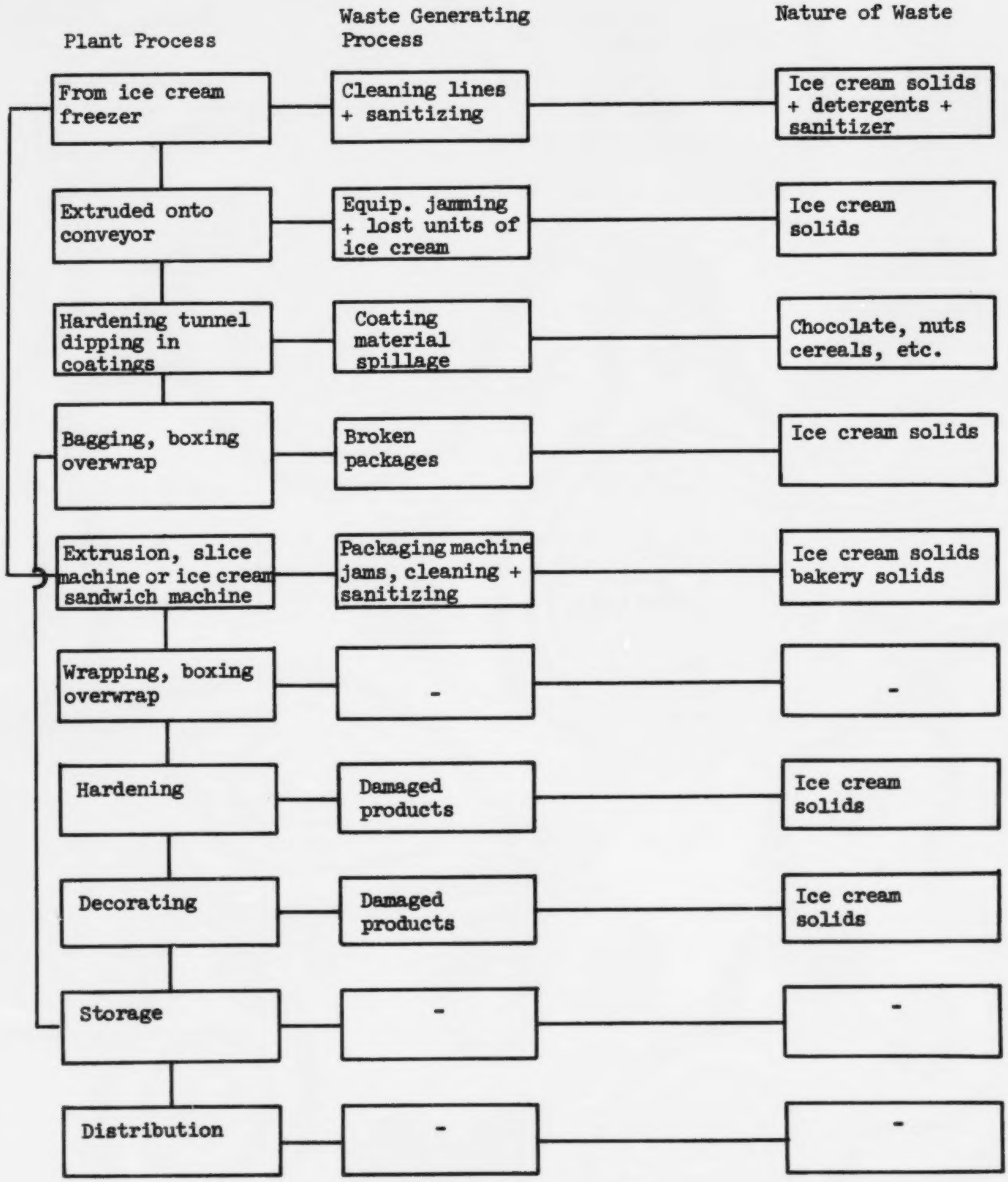
Plant Process	Waste Generating Processes	Nature of Waste
Receiving and storage	Washing tank trucks & storage tanks	Milk wastes + sugar solids detergent + sanitizer
Standardizing	Separator sludge + cleaning sanitizing	High protein & cellular material
Dry ingredient blending	Ingredient spillage sanitizing	High solids milk waste
Mixing	Process vat, cleaning sanitizing	Milk wastes + detergent + sanitizer
HTST Pasteurizing & homogenization	HTST start-up change over and cleaning	Ice cream mix wastes + detergent + sanitizer
Cooling and storage	Cleaning lines and storage sanitizing	Ice cream mix wastes + detergent sanitizer
Flavoring fruits, nuts	Spillage and fruit feeder cleaning	Fruits, nuts, ice and flavorings
Freezing	Product change over & cleaning sanitizing	Ice cream mix fruits, nuts, flavorings, + detergents sanitizers
Filling and conveying	Filling machine jams, broken packages, cleaning + sanitizing conveying	Ice cream mix fruits, nuts, flavorings, + detergents sanitizers lubricants
Hardening and distribution	Broken packages	Ice cream solids

Flow Diagram 12 - Ice Cream

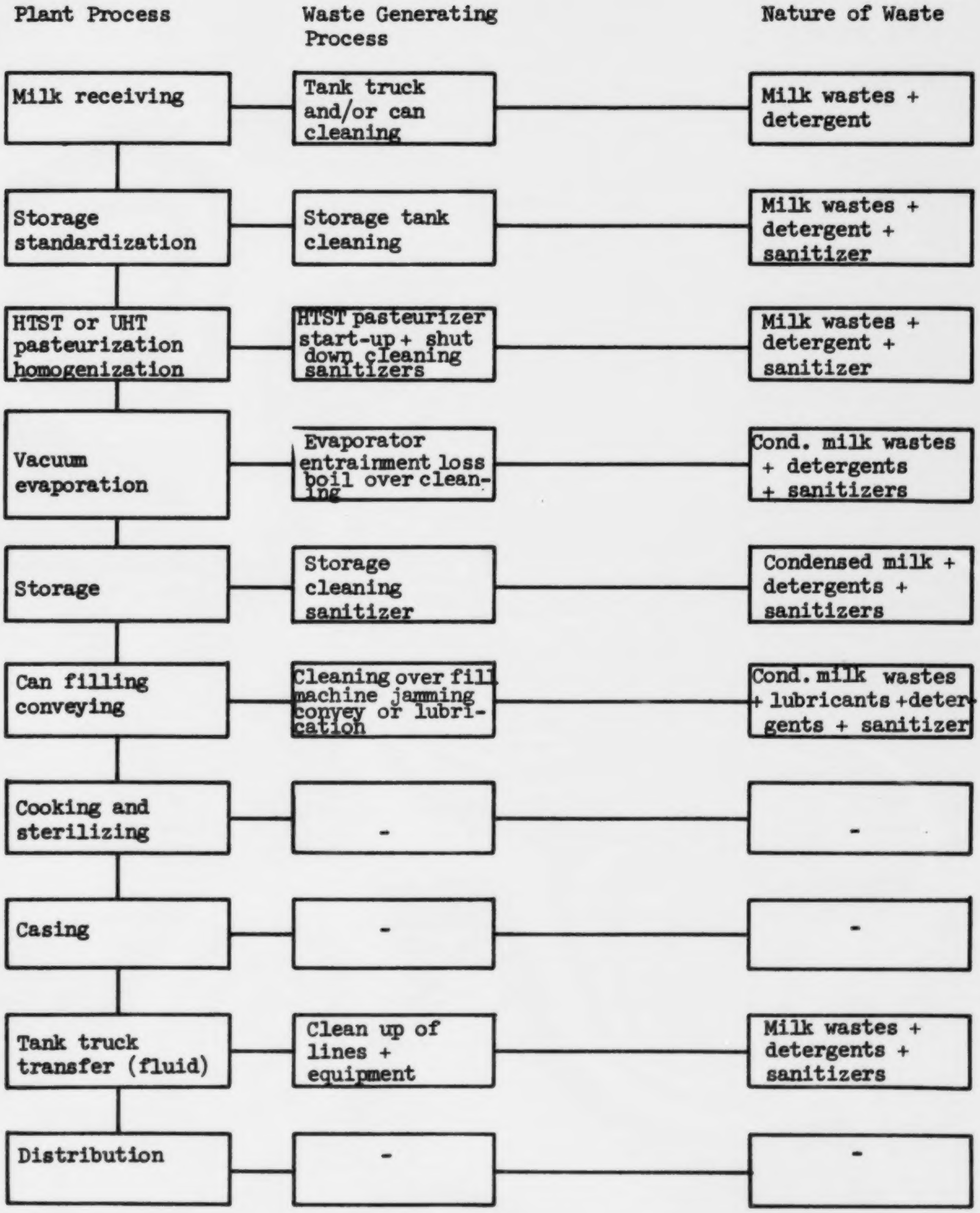


Unit Plant Process	Waste Generating Process	Nature of Waste
Mix storage	Cleaning storage tanks	Ice cream mix + detergents + sanitizers
Ice cream freezer	Cleaning + sanitizers	Ice cream mix + detergents + sanitizers
To molds in refrigerated tanks	Machine jamming	Ice cream mix, wastes
Hardening	Brine replacement	Salt, ice cream mix solids
Dipping in coating	Dipping, product damage	Choc. coating ice cream fruit juice solids
Bagging	Broken packages	Choc. coating ice cream fruit juice solids
Storage	Broken packages	Choc. coating ice cream fruit juice solids
Distribution	Returns	Ice cream solids fruits + nuts

Flow Diagram 13 - Ice Cream-Subprocess Stick Novelties

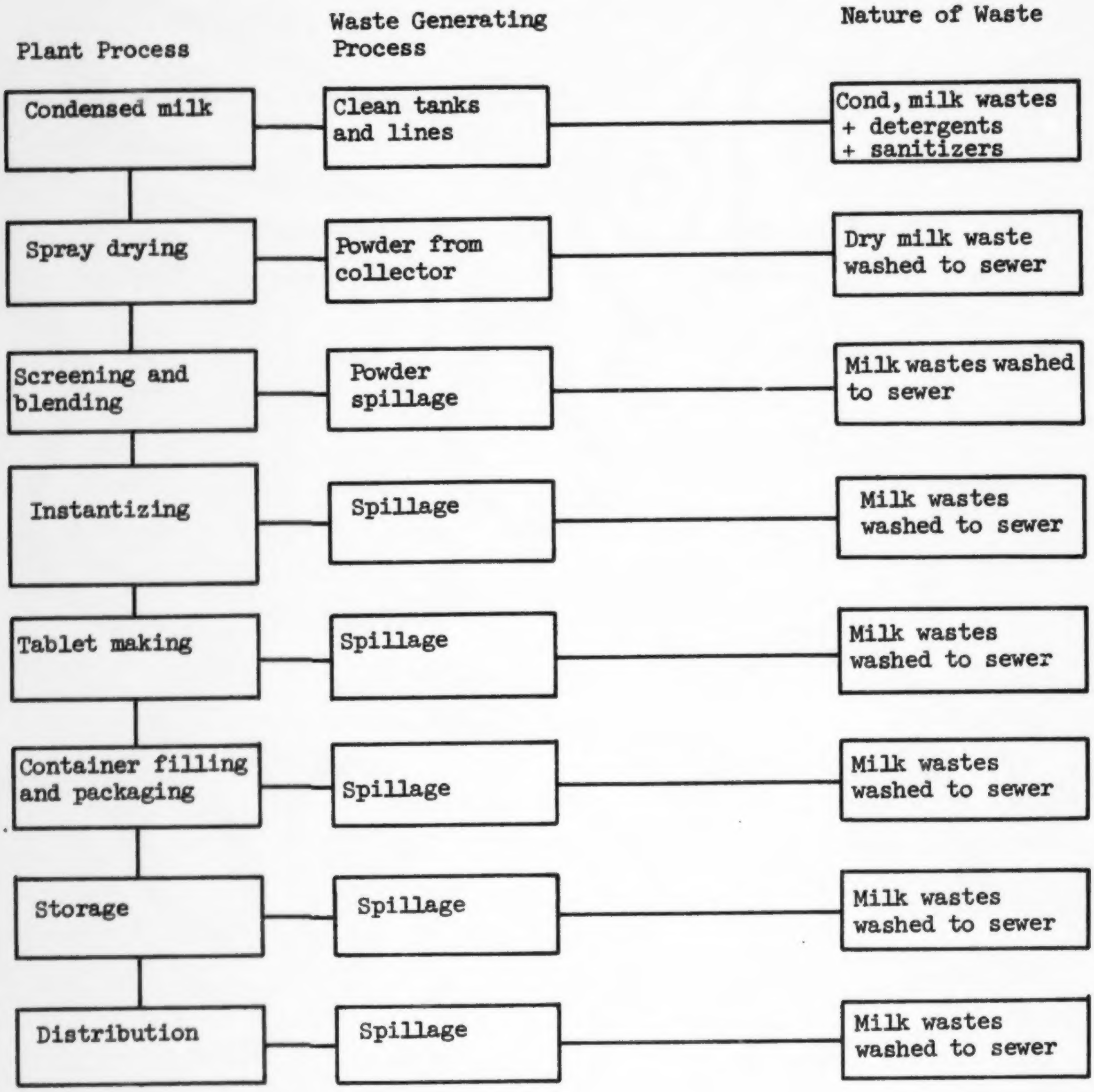

Plant Process
Waste Generating Process
Nature of Waste
From ice cream freezer
Cleaning lines + sanitizing
Ice cream solids + detergents + sanitizer
Extruded onto conveyor
Equip. jamming + lost units of ice cream
Ice cream solids
Hardening tunnel dipping in coatings
Coating material spillage
Chocolate, nuts cereals, etc.
Bagging, boxing overwrap
Broken packages
Ice cream solids
Extrusion, slice machine or ice cream sandwich machine
Packaging machine jams, cleaning + sanitizing
Ice cream solids bakery solids
Wrapping, boxing overwrap
-
-
Hardening
Damaged products
Ice cream solids
Decorating
Damaged products
Ice cream solids
Storage
-
-
Distribution
-
-

Flow Diagram 14 - Ice Cream-Subprocess-Stickless Novelties



Plant Process	Waste Generating Process	Nature of Waste
Milk receiving	Tank truck and/or can cleaning	Milk wastes + detergent
Storage standardization	Storage tank cleaning	Milk wastes + detergent + sanitizer
HTST or UHT pasteurization homogenization	HTST pasteurizer start-up + shut down cleaning sanitizers	Milk wastes + detergent + sanitizer
Vacuum evaporation	Evaporator entrainment loss boil over cleaning	Cond. milk wastes + detergents + sanitizers
Storage	Storage cleaning sanitizer	Condensed milk + detergents + sanitizers
Can filling conveying	Cleaning over fill machine jamming convey or lubrication	Cond. milk wastes + lubricants + detergents + sanitizer
Cooking and sterilizing	-	-
Casing	-	-
Tank truck transfer (fluid)	Clean up of lines + equipment	Milk wastes + detergents + sanitizers
Distribution	-	-

Flow Diagram 15 - Condensed Milk Process


Plant Process
Waste Generating Process
Nature of Waste
Condensed milk
Clean tanks and lines
Cond, milk wastes + detergents + sanitizers
Spray drying
Powder from collector
Dry milk waste washed to sewer
Screening and blending
Powder spillage
Milk wastes washed to sewer
Instantizing
Spillage
Milk wastes washed to sewer
Tablet making
Spillage
Milk wastes washed to sewer
Container filling and packaging
Spillage
Milk wastes washed to sewer
Storage
Spillage
Milk wastes washed to sewer
Distribution
Spillage
Milk wastes washed to sewer

Flow Diagram 16 - Spray Drying Process

Table 46 - Coefficient Water Use for Various Plant Operations

Operation	Pounds of Water/Pounds of Milk Processed
Can washing	0.001
Truck washing	0.07
Cooling milk in storage	0.2
Pasteurization	0.35
Bottle washer	0.5
Boilers & Evaporators	0.25
Cleaning	0.25
Spray cleaning tanks	
Pre-rinses	0.005
Cleaning	0.010
Post-rinse	0.005
Sanitizing	0.005
Lines	
Pre-rinse	0.0005
Cleaning	0.001
Post-rinse	0.0005
Sanitizing	0.025
Evaporating (3:1) (triple effect) Calander cond.	9.0
Condensing (triple effect) Plate cond.	12.0
Cottage cheese wash water	1.2
Cooling	
Receiving, bottling, ice cream & cream cheese	1.2
Receiving past. separating, condensing & spray drying	1.1 - 1.5
Receiving cond. canning & sterilizing	0.02- 0.4

Table 47 - Average Reported/BOD Losses for Various Dairy Food Plant Unit Operations

Process	Pounds BOD/1000 Pounds Milk Processed				
	Trebler & Harding, 1947	Trebler & Harding, 1949	MIF Manual, 1967	Scotland 1968	Royal 1968
Receiving and cooling milk	0.6	0.4	0.2	0.25	0.65
Tanker delivery, washing	0.1	0.1	0.1	0.25	--
Storage of milk in tanks	0.1	0.1	0.05	0.18	--
Cream separating	0.4	0.2	0.2	0.13	--
Cream pasteurization, cooling, filling	0.4	0.2	0.2	0.75	0.96*
Cream separation and pasteurization	--	--	--	0.65	--
Skim milk past, cooling, can filling	--	0.2	0.2	--	--
Milk pasteurization and storage	--	--	--	0.29	--
Milk past., storage and bottling (glass)	0.8	0.8	0.8	0.85	1.08
Milk past., storage and bottling (paper)	--	0.6	0.6	--	--
Bottling pasteurized milk	--	--	--	0.11	--
Glass bottle washing	--	--	--	0.23	--
Cottage cheese (casein) mfg.	1.6	1.6	4.7	15.0	--
Cheese (pressed) mfg. (unwashed curd)	--	--	0.8	--	0.89
Evaporating whole milk					
Floor waste	0.3	0.2	0.2	--	--
Entrainment losses	0.2	0.1	0.1	--	--
Evaporating skim milk	--	--	--	0.23	--
Canning sterilizing evap. milk	0.3	0.2	0.2	--	1.08**
Condensing whey (2:1)	--	--	--	0.29	--
Condensing whey (3:1)	--	--	--	1.40	1.92
Sweet whey					
Floor wastes	0.8	0.8	0.8	--	--
Condensate	0.4	.4	0.4	0.75	--
Washing condenser	--	--	--	0.60	--
Acid whey					
Floor wastes	0.8	0.8	0.8	--	--
Condensate	0.4	0.3	0.3	0.60	--

Table 47 (Continued)

Process	Pounds BOD/1000 Pounds Milk Processed				
	Trebler & Harding, 1947	Trebler & Harding, 1949	MIF Manual, 1967	Scotland 1968	Royal 1968
Condensing sweetened condensed skim milk	--	--	--	1.40	--
Floor wastes	0.6	0.3	0.3	--	--
Entrainment loss	0.3	0.05	0.05	--	--
Condensing & canning sweetened milk	--	--	--	--	1.32
Supercondensing skim	1.2	1.2	1.2	--	--
Spray drying whole milk	0.2	0.1	0.1	--	--
Roller drying	--	--	--	0.51	1.80
Evaporating skim and drying	--	--	--	0.74	1.02
Whey drying	0.6	0.5	0.5	--	--
Ice cream making and filling	--	--	--	1.60	--
Ice cream making, pan	0.6	0.4	0.4	--	--
Ice cream making, vat	0.6	0.4	0.4	--	--
Ice cream freezing	0.2	0.05	0.05	--	--
Cultured buttermilk making	1.0	0.5	0.5	--	--
Sour cream mfg.	--	--	--	1.2	--
Butter churning and washing	0.6	0.2	0.2	0.46	0.72

*Includes separation

**Includes condensing

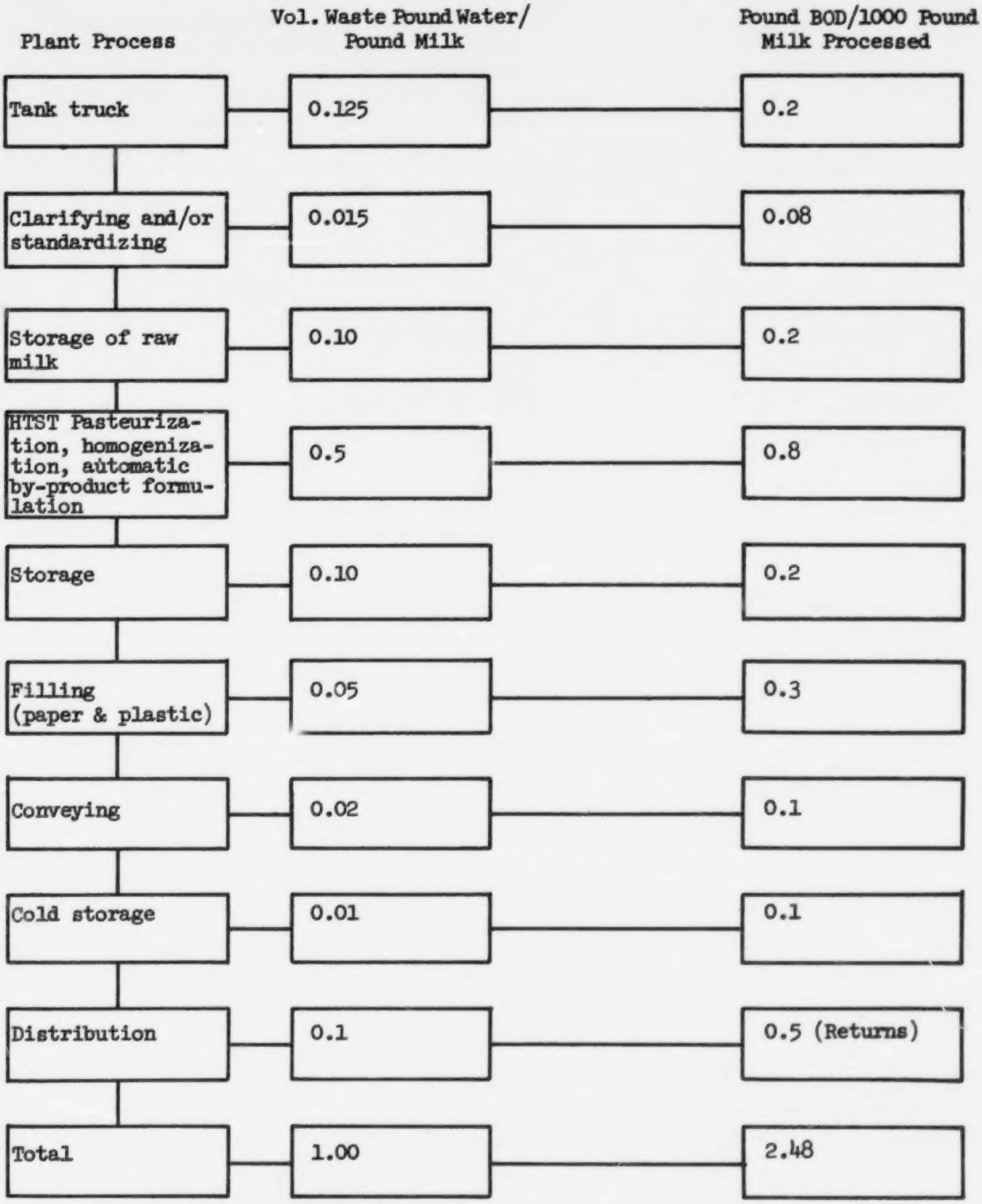
During the course of this investigation data was obtained from two different modern automated dairy plants, both producing milk and cottage cheese, as shown in Table 48. Based on industry observation and evaluation of literature data, volume and BOD coefficients per thousand pounds of milk processed (or milk equivalent) for various operations are presented in Flow Diagrams 17-31. The data should be considered as guides only, which would require a relatively good management to achieve, and may be expected to vary from plant to plant. Much more data on specific unit operations of different type plants measured under controlled conditions is needed to provide a truly reliable index of the roll of various unit operations in waste loading.

Table 48 - Industrial Data for BOD Coefficients for Unit Processes in Two Fluid Milk, Cottage Cheese Plants

Process	Pounds of BOD/1000 Pounds of Milk Received	
	Plant A	Plant B
Tank truck rinsings	0.25	--
Silo tank rinsings	0.23	--
Tank trucks and storage tank rinsings	--	0.25
Separation (CIP)	0.15	--
CIP Separator sludge	--	0.08
HTST start-up and change-over and cleaning	0.75*	0.55
Filling operations-milk	0.30	0.32
Lubricants	--	0.08
Product returns	--	0.10
Cottage cheese wash water	0.33	0.60
Unaccounted	0.20	0.03
TOTAL WASTE WATER	2.16	2.01

*Initial start-up collected, product change-overs not diverted

Flow Diagram 17 depicts the waste water volume and BOD_5 coefficients for the various unit operation of the fluid milk operation under good



Plant Process	Vol. Waste Pound Water/ Pound Milk	Pound BOD/1000 Pound Milk Processed
Tank truck	0.125	0.2
Clarifying and/or standardizing	0.015	0.08
Storage of raw milk	0.10	0.2
HTST Pasteurization, homogenization, automatic by-product formulation	0.5	0.8
Storage	0.10	0.2
Filling (paper & plastic)	0.05	0.3
Conveying	0.02	0.1
Cold storage	0.01	0.1
Distribution	0.1	0.5 (Returns)
Total	1.00	2.48

Flow Diagram 17 - Waste Coefficients -- Market Milk
(normal operation)

management, with no extra steps taken to eliminate wastes. Flow Diagram 18 shows the same process after the elimination of all rinses, product from start-up, change over and shut-down of the HTST unit, collection of all spillage from filling operations and elimination of all returns from the waste stream. The resulting coefficients are < 0.5, and indicate what can be done through management and engineering control.

Subsequent flow diagrams show the coefficients predicted under normal good management for the operations previously presented in flow diagrams for various dairy food plants.

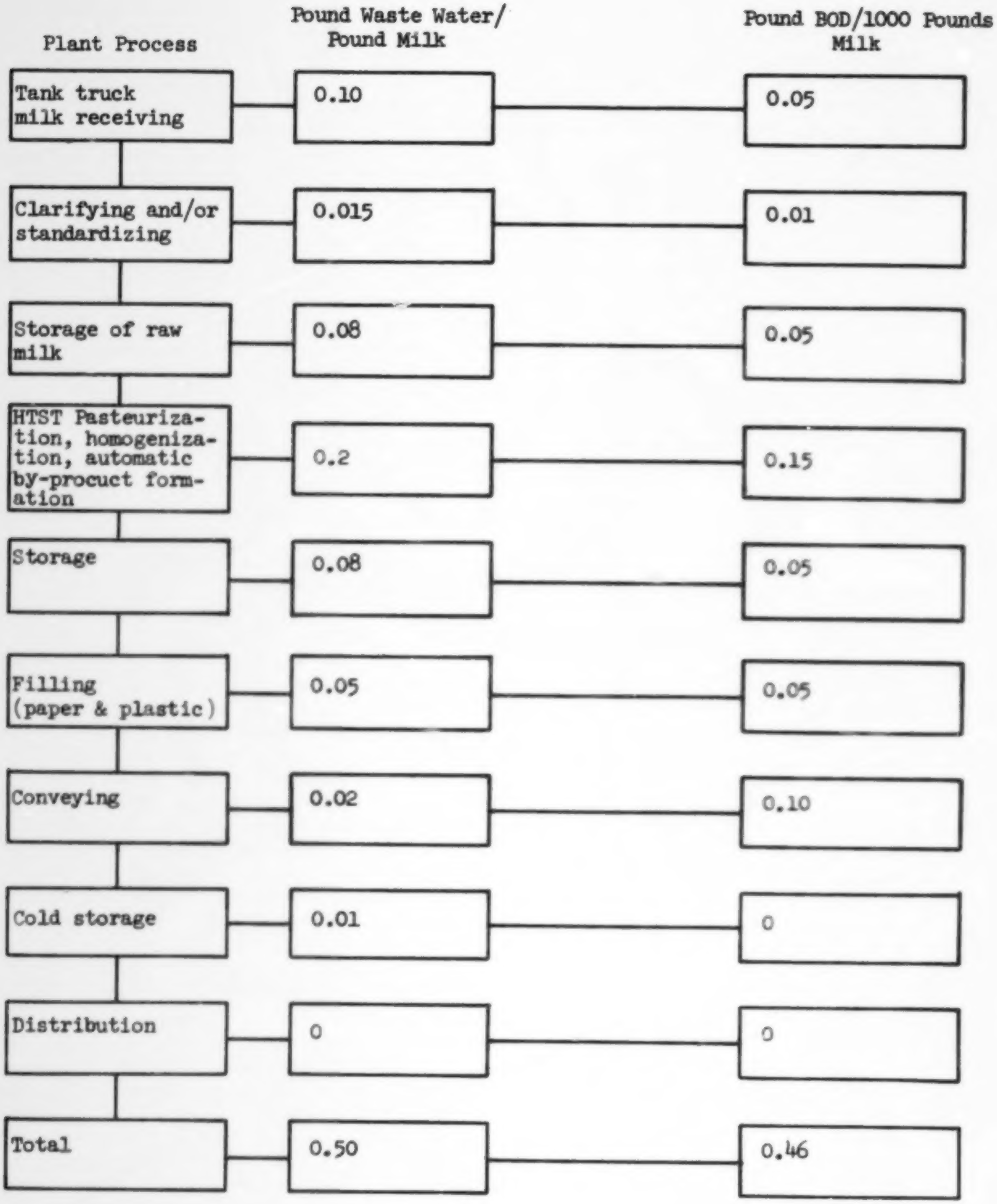
In determining the over-all waste coefficients for various types of plants, corrections were made to compensate for the amounts of waste water or BOD generated by the various processes for each unit weight of milk processed. For example, in cheese operations, the starter manufacturing process generates about 0.1 pound of water per pound of product and about 0.3 pound of BOD/10,000 pounds of milk processed. However, starter is used at the rate of 1.0%; thus, this operation would contribute only 0.01 pound of water/pound of milk processed and 0.03 pound of BOD/1000 pounds of milk processed into cheese.

The coefficients for all operations can be reduced in the same manner as illustrated for fluid milk operations. The values reported by some of the plants surveyed during this study had coefficients materially below those reported in the various flow sheets.

Waste from Individual Unit Operations

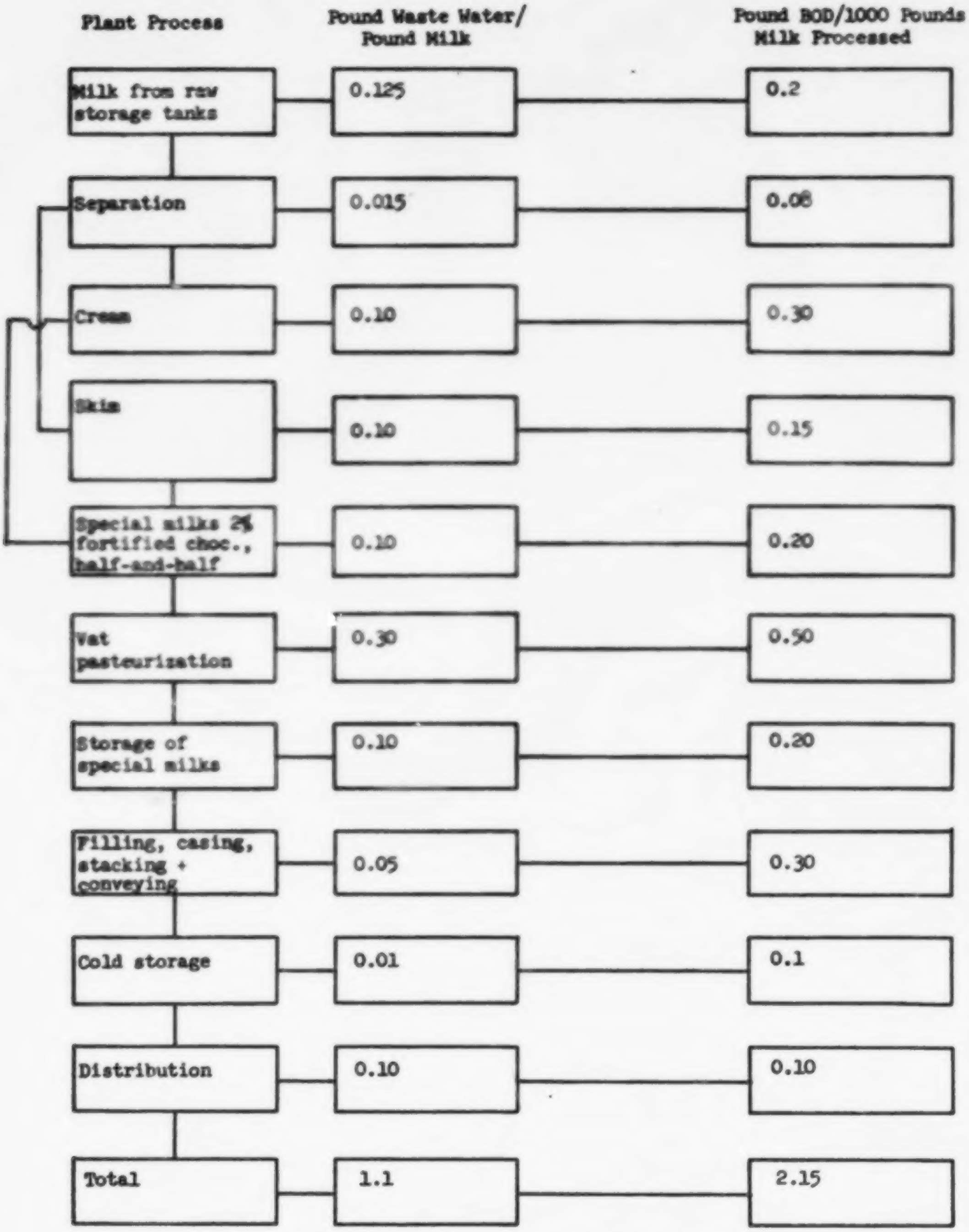
Cottage Cheese Operations: Data in Table 49 show the BOD coefficients for two cottage cheese operations based on information concerning the BOD values of various cheese wash waters. The concentration, percentage volume of original whey, and BOD of whey wash water and fines available from one industrial plant is presented in Table 50. These data represent values from four vats. The values are in relatively good agreement with the values in the preceding table and further illustrate the significance of solid casein particles on BOD and the necessity that these materials be excluded from the operations. Careful draining and a partial pre-rinse can reduce the BOD to approximately 50% of the values shown. The pounds of BOD in the wash water are about 33% of the pounds of BOD in the whey.

Over the years, industry has utilized whey as a means of cooling curd instead of wash water, thus minimizing the amount of whey required. Although this was done originally to avoid contamination of the cheese with spoilage microorganisms, the same can be accomplished today to reduce both the volume and BOD strength of wash water. The practice was to pump the whey into the vat, put it through a heat exchanger in two stages to bring the temperature of the curd down to about 50°F. The curd was then thoroughly drained and washed with a volume equal to one-half of that of whey as a final wash to reduce acid flavor in the cheese. Utilization of such a procedure could reduce the BOD level in wash water diluted solids down to about 50% of current levels.



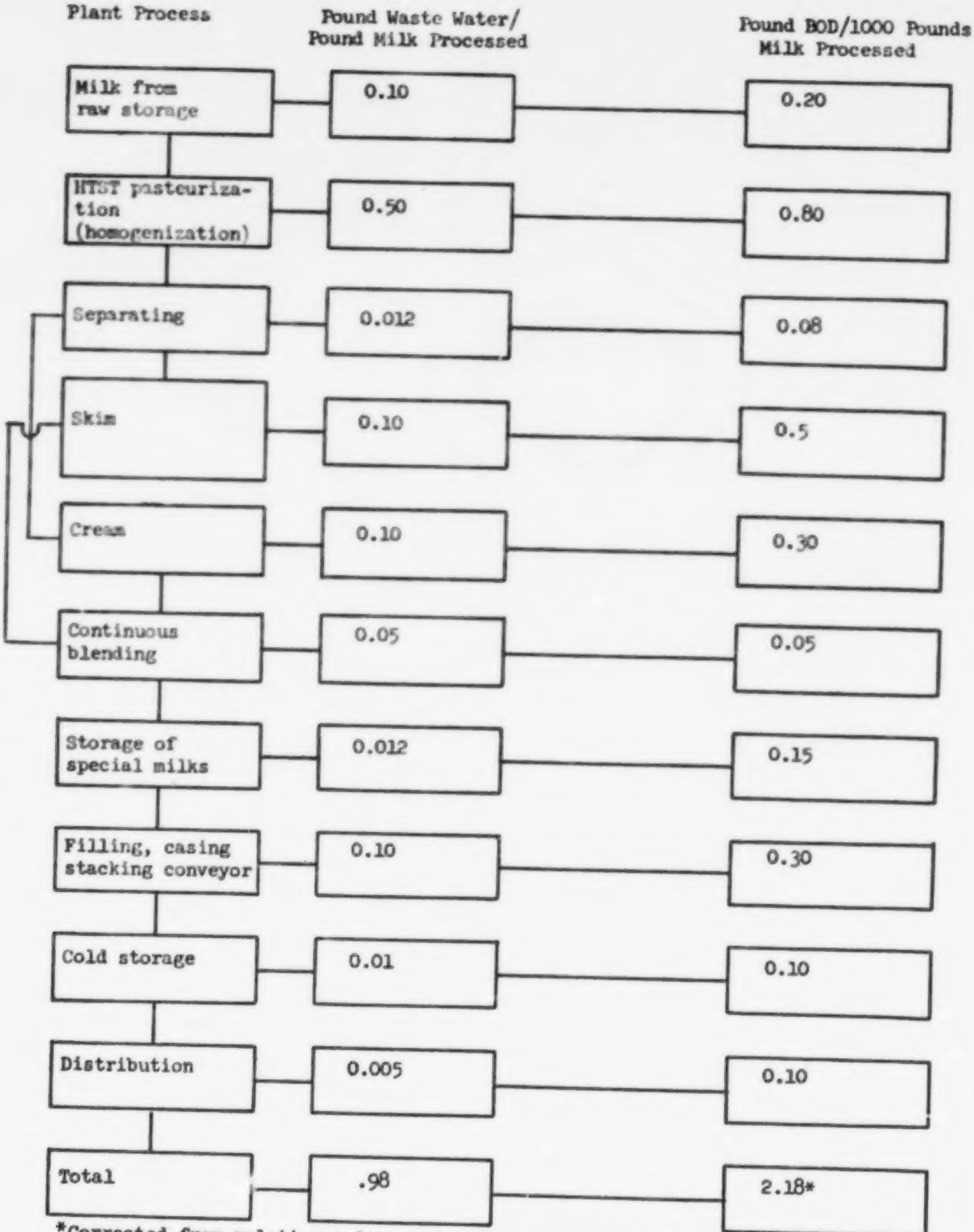
Plant Process	Pound Waste Water/ Pound Milk	Pound BOD/1000 Pounds Milk
Tank truck milk receiving	0.10	0.05
Clarifying and/or standardizing	0.015	0.01
Storage of raw milk	0.08	0.05
HTST Pasteurization, homogenization, automatic by-procuct formation	0.2	0.15
Storage	0.08	0.05
Filling (paper & plastic)	0.05	0.05
Conveying	0.02	0.10
Cold storage	0.01	0
Distribution	0	0
Total	0.50	0.46

Flow Diagram 18 - Waste Coefficients--Market Milk (rinses saved) CIP Sludge Saved, HTST Start-Up, Change-Over and Shut-Down Segregated and Saved: Returns Used as Feed



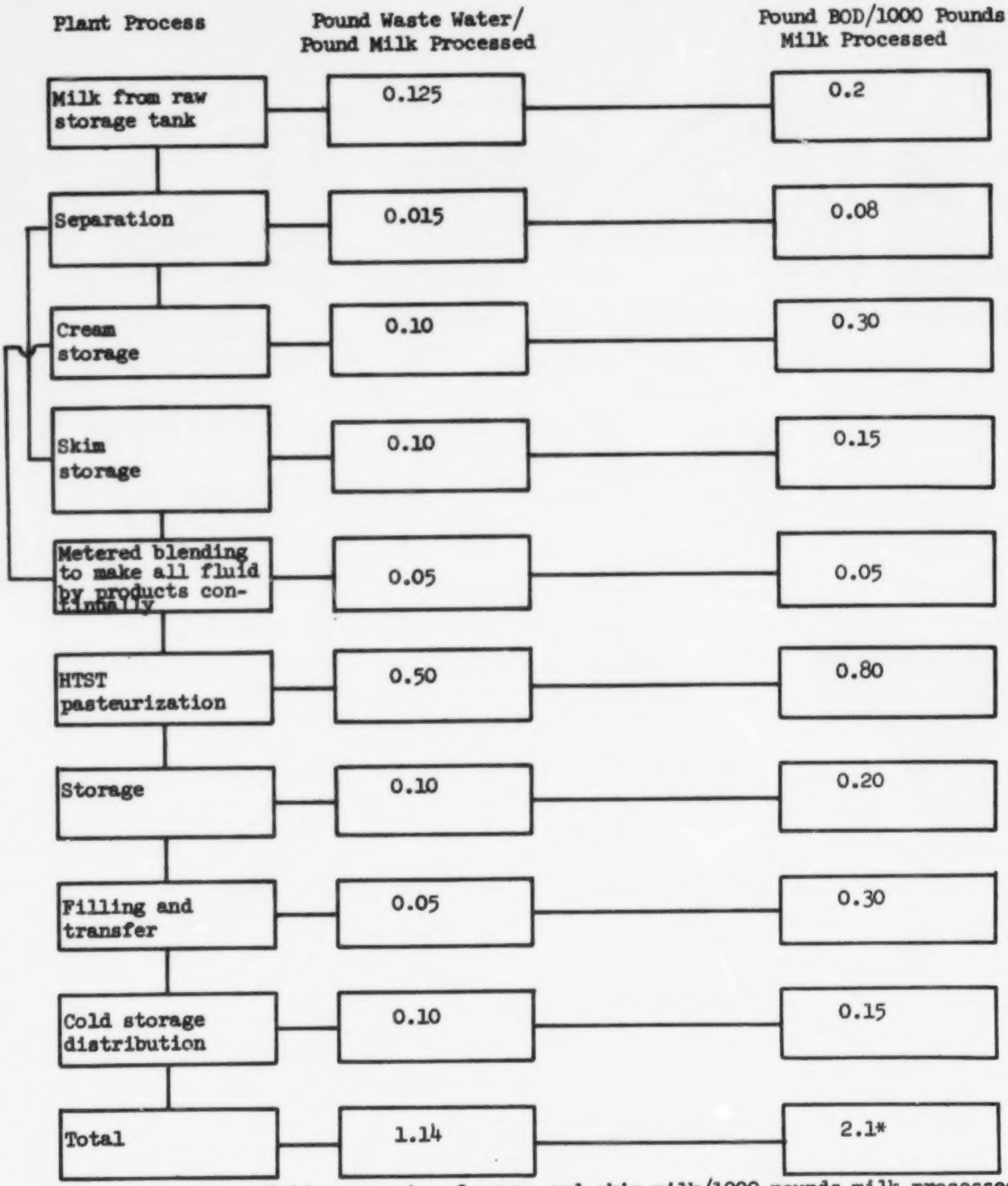
Plant Process	Pound Waste Water/ Pound Milk	Pound BOD/1000 Pounds Milk Processed
Milk from raw storage tanks	0.125	0.2
Separation	0.015	0.08
Cream	0.10	0.30
Skim	0.10	0.15
Special milks 2% fortified choc., half-and-half	0.10	0.20
Vat pasteurization	0.30	0.50
Storage of special milks	0.10	0.20
Filling, casing, stacking + conveying	0.05	0.30
Cold storage	0.01	0.1
Distribution	0.10	0.10
Total	1.1	2.15

Flow Diagram 19 - Waste Coefficients-Market Milk-Subprocess-Skim Milk, Creams and Special Milks by Batch Processing-Alternate 1


Plant Process
Pound Waste Water/ Pound Milk Processed
Pound BOD/1000 Pounds Milk Processed
Milk from raw storage
0.10
0.20
HTST pasteurization (homogenization)
0.50
0.80
Separating
0.012
0.08
Skim
0.10
0.5
Cream
0.10
0.30
Continuous blending
0.05
0.05
Storage of special milks
0.012
0.15
Filling, casing stacking conveyor
0.10
0.30
Cold storage
0.01
0.10
Distribution
0.005
0.10
Total
.98
2.18*

*Corrected from relative volumes of cream and skim milk/1000 pounds milk processed

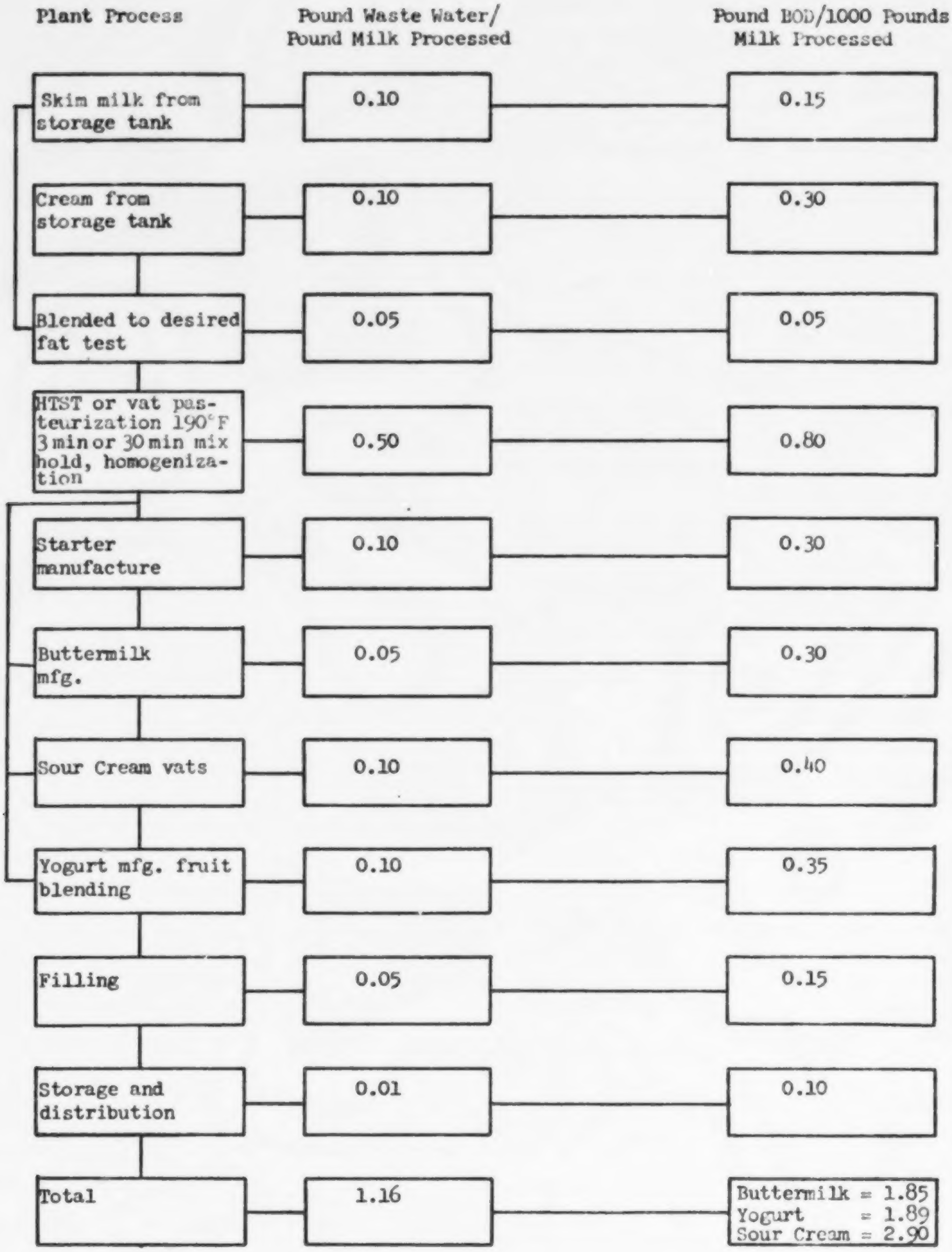
Flow Diagram 20 - Waste Coefficients Market Milk-Subprocess-Skim Milk Creams and Special Milks by Continuous Process-Alternate 2



Plant Process	Pound Waste Water/ Pound Milk Processed	Pound BOD/1000 Pounds Milk Processed
Milk from raw storage tank	0.125	0.2
Separation	0.015	0.08
Cream storage	0.10	0.30
Skim storage	0.10	0.15
Metered blending to make all fluid by products continually	0.05	0.05
HTST pasteurization	0.50	0.80
Storage	0.10	0.20
Filling and transfer	0.05	0.30
Cold storage distribution	0.10	0.15
Total	1.14	2.1*

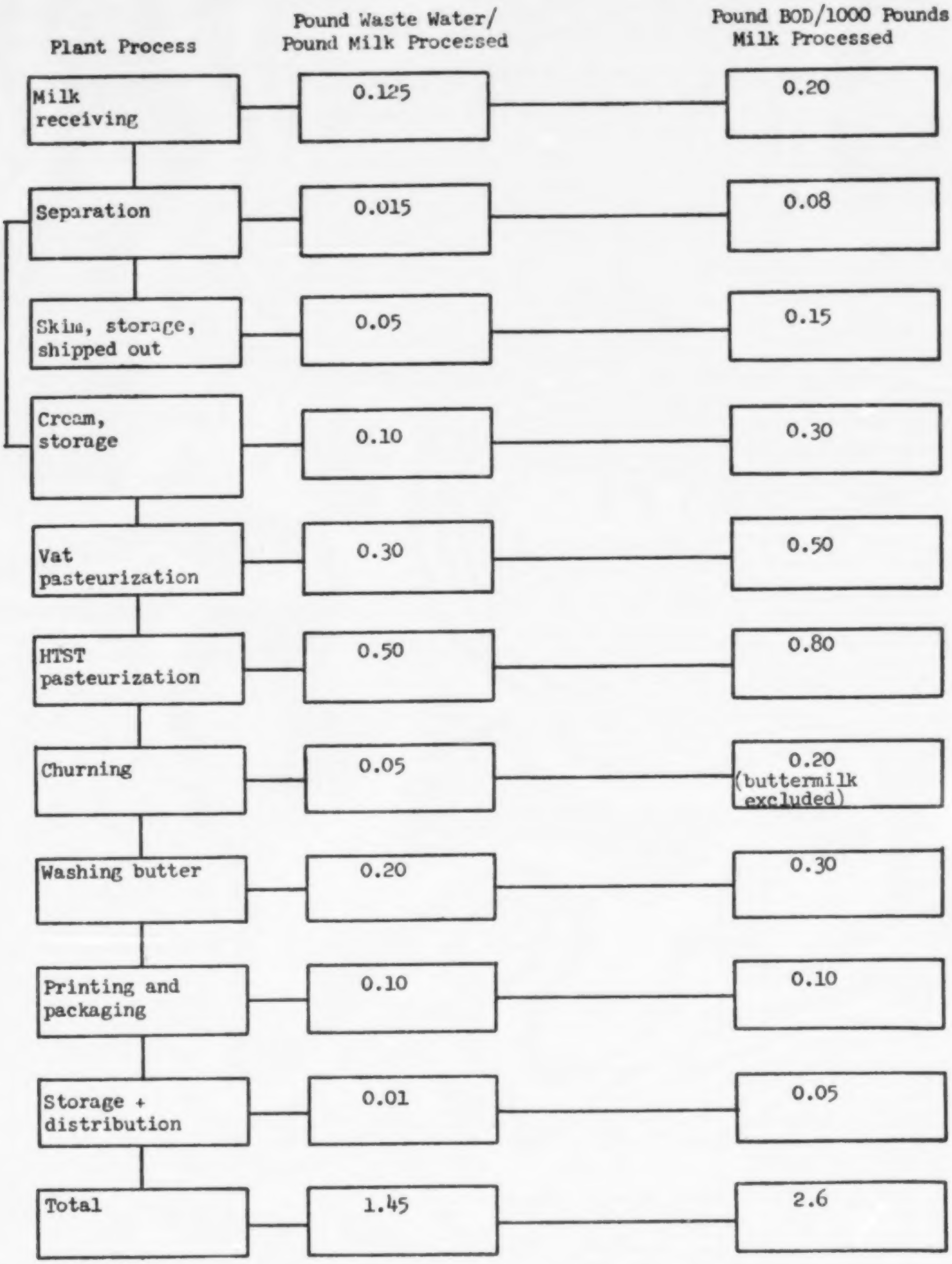
*Corrected for relative amounts of cream and skim milk/1000 pounds milk processed

Flow Diagram 21 - Waste Coefficients Market Milk-Subprocesses-Skim Milk Creams & Special Milks by Continuous Process Alternated



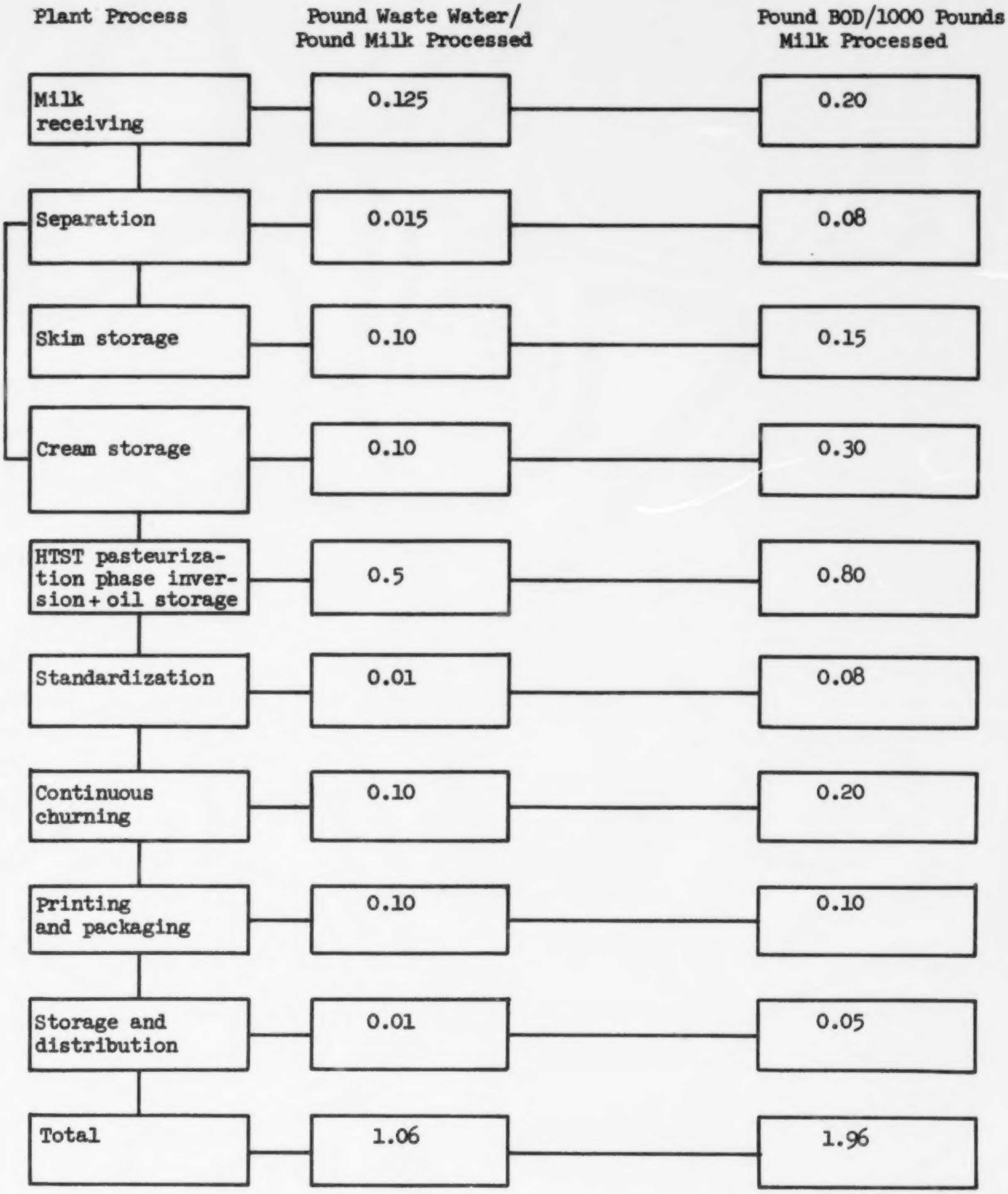
Plant Process	Pound Waste Water/ Pound Milk Processed	Pound BOD/1000 Pounds Milk Processed
Skim milk from storage tank	0.10	0.15
Cream from storage tank	0.10	0.30
Blended to desired fat test	0.05	0.05
HTST or vat pasteurization 190°F 3 min or 30 min mix hold, homogenization	0.50	0.80
Starter manufacture	0.10	0.30
Buttermilk mfg.	0.05	0.30
Sour Cream vats	0.10	0.40
Yogurt mfg. fruit blending	0.10	0.35
Filling	0.05	0.15
Storage and distribution	0.01	0.10
Total	1.16	Buttermilk = 1.85 Yogurt = 1.89 Sour Cream = 2.90

Flow Diagram 22 - Market Milk-Subprocesses: Buttermilk, and Yogurt Sour Cream



Plant Process	Pound Waste Water/ Pound Milk Processed	Pound BOD/1000 Pounds Milk Processed
Milk receiving	0.125	0.20
Separation	0.015	0.08
Skim, storage, shipped out	0.05	0.15
Cream, storage	0.10	0.30
Vat pasteurization	0.30	0.50
HTST pasteurization	0.50	0.80
Churning	0.05	0.20 (buttermilk excluded)
Washing butter	0.20	0.30
Printing and packaging	0.10	0.10
Storage + distribution	0.01	0.05
Total	1.45	2.6

Flow Diagram 23 - Waste Coefficients-Butter-Churn Process



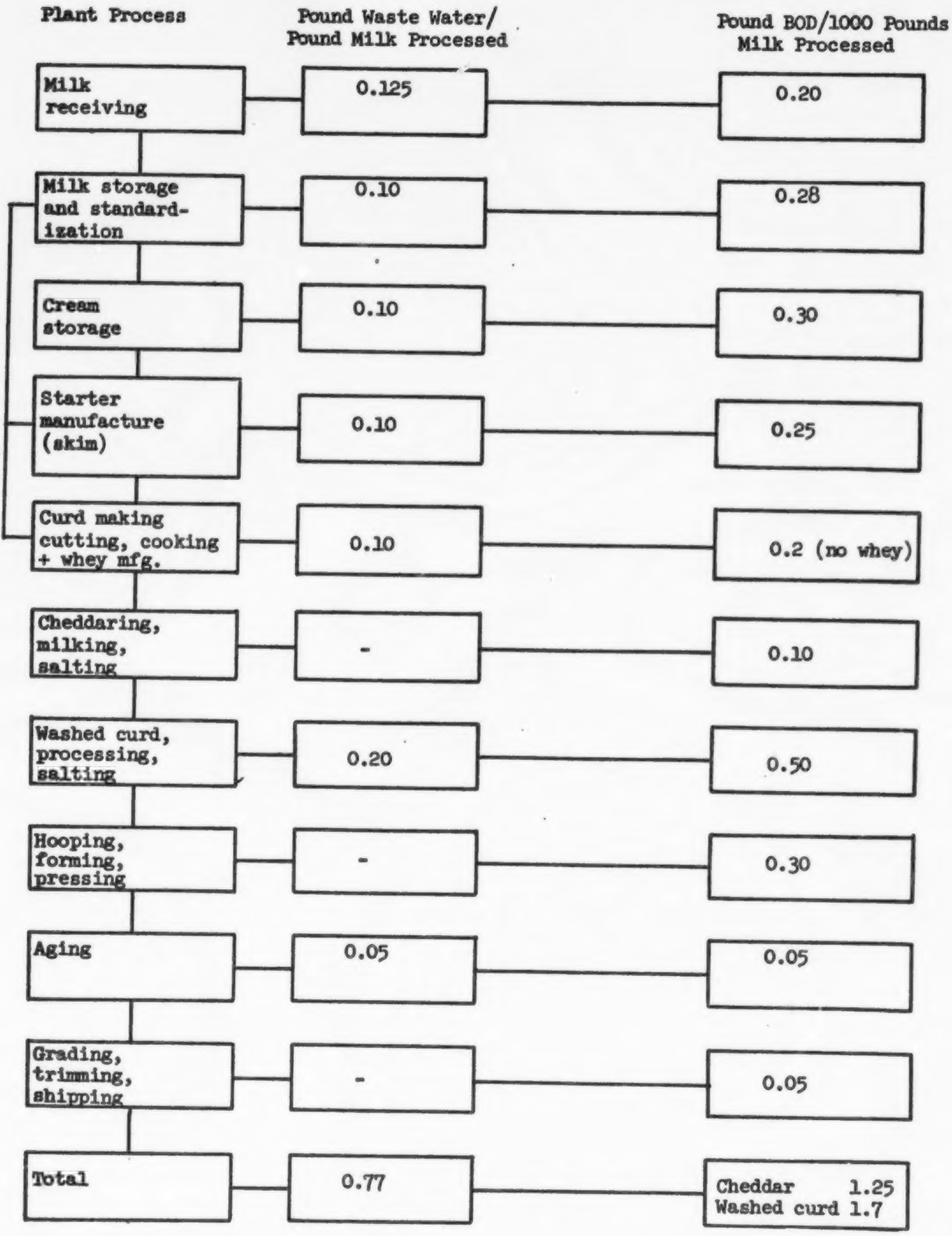
Plant Process	Pound Waste Water/ Pound Milk Processed	Pound BOD/1000 Pounds Milk Processed
Milk receiving	0.125	0.20
Separation	0.015	0.08
Skim storage	0.10	0.15
Cream storage	0.10	0.30
HTST pasteurization phase inversion + oil storage	0.5	0.80
Standardization	0.01	0.08
Continuous churning	0.10	0.20
Printing and packaging	0.10	0.10
Storage and distribution	0.01	0.05
Total	1.06	1.96

Flow Diagram 24 - Waste Coefficients-Butter-Continuous Process

Plant Process	Pound Waste Water/ Pound Milk Processed	Pound BOD/1000 Pounds Milk Processed
Skim Milk from separator	0.01	0.08
HTST pasteurization	0.50	0.70
Starter manufacture	0.10	0.30
Settling, cutting, cooking, draining	0.20	0.20 (no whey)
Washing three times	10.0	1.5
Cooling	0.5	0.1
Cream from past. storage	0.125	0.30
Creaming	0.10	0.30
Packaging	0.05	0.10
Storage and distribution	0.01	0.10
Total	11.6	2.85*

*Corrected for amount of starter and cream used

Flow Diagram 25 - Cottage Cheese

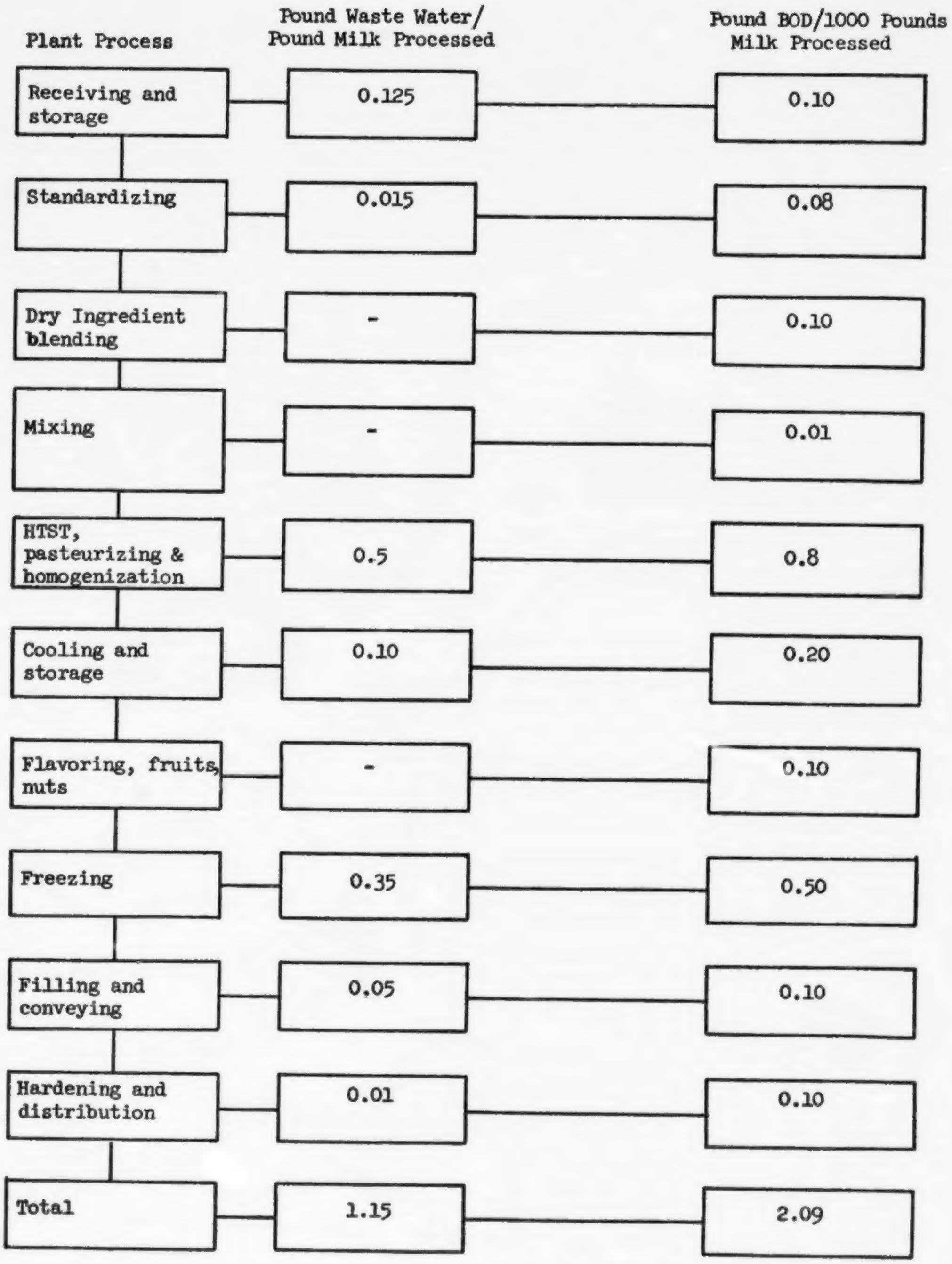


Plant Process	Pound Waste Water/ Pound Milk Processed	Pound BOD/1000 Pounds Milk Processed
Milk receiving	0.125	0.20
Milk storage and standardization	0.10	0.28
Cream storage	0.10	0.30
Starter manufacture (skim)	0.10	0.25
Curd making cutting, cooking + whey mfg.	0.10	0.2 (no whey)
Cheddaring, milking, salting	-	0.10
Washed curd, processing, salting	0.20	0.50
Hooping, forming, pressing	-	0.30
Aging	0.05	0.05
Grading, trimming, shipping	-	0.05
Total	0.77	Cheddar 1.25 Washed curd 1.7

Flow Diagram 26 - Waste Coefficients-Cheddar Cheese Manufacture

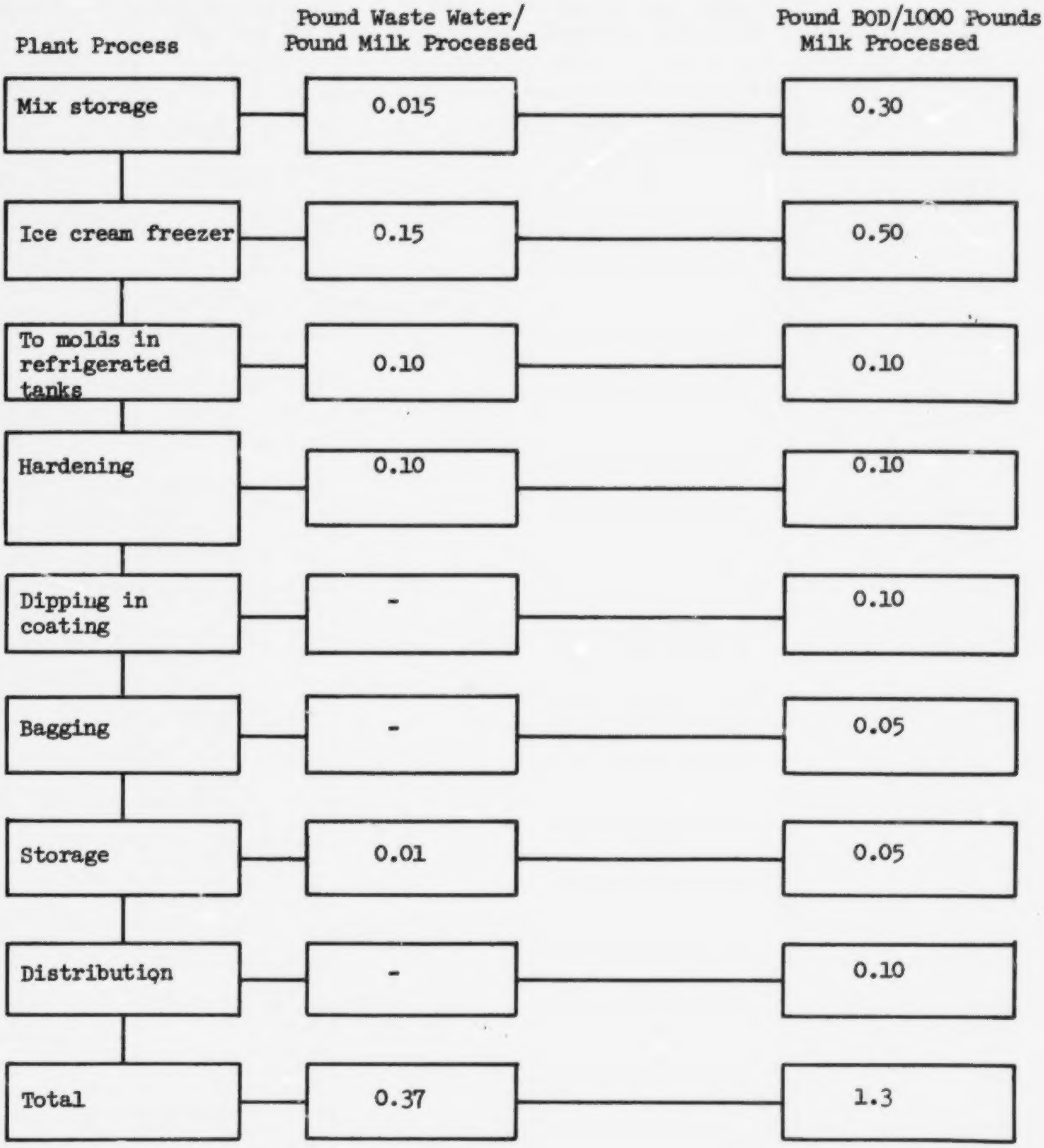
Plant Process	Pound Waste Water/ Pound Milk Processed	Pound BOD/1000 Pounds Milk Processed
Milk receiving	0.125	0.20
Storage standardization	0.012	0.18
Cream storage	0.10	0.30
Starter mfg.	0.10	0.30
Curd making, cutting, cooking draining	0.20	0.20 (no whey)
Curd stretching + texturizing (filata)	0.30	0.30
Mixing molding	0.10	0.30
Brine salting	0.15	0.05
(Smoking) aging	-	0.01
Trimming, distribution	0.01	0.10
Total	1.09	1.37

Flow Diagram 27 - Waste Coefficients-Cheese-Pasta Filata (Provolone, Mozzarella) Cheese Manufacture



Plant Process	Pound Waste Water/ Pound Milk Processed	Pound BOD/1000 Pounds Milk Processed
Receiving and storage	0.125	0.10
Standardizing	0.015	0.08
Dry Ingredient blending	-	0.10
Mixing	-	0.01
HTST, pasteurizing & homogenization	0.5	0.8
Cooling and storage	0.10	0.20
Flavoring, fruits, nuts	-	0.10
Freezing	0.35	0.50
Filling and conveying	0.05	0.10
Hardening and distribution	0.01	0.10
Total	1.15	2.09

Diagram 28 - Waste Coefficients-Ice Cream

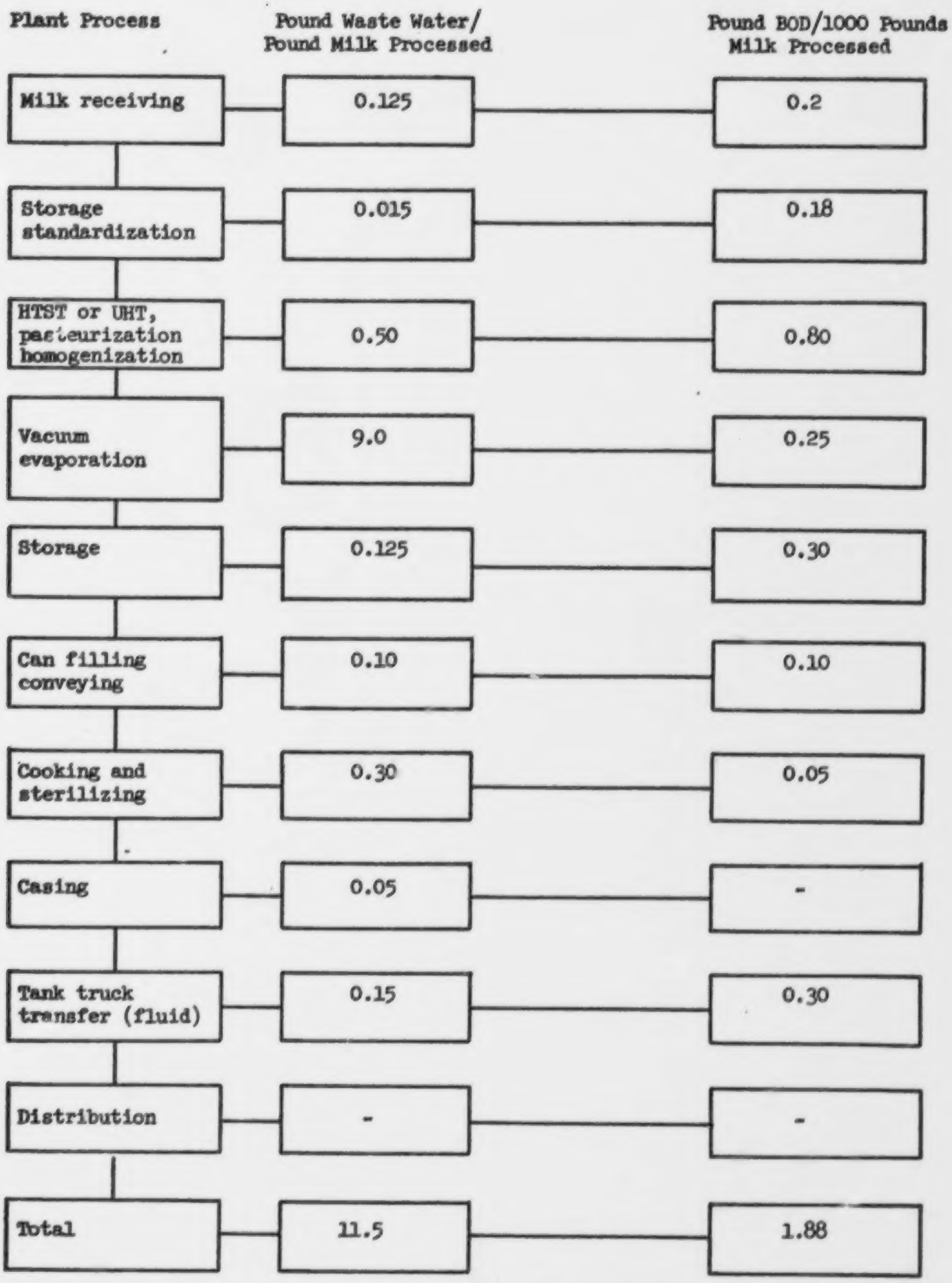


Plant Process	Pound Waste Water/ Pound Milk Processed	Pound BOD/1000 Pounds Milk Processed
Mix storage	0.015	0.30
Ice cream freezer	0.15	0.50
To molds in refrigerated tanks	0.10	0.10
Hardening	0.10	0.10
Dipping in coating	-	0.10
Bagging	-	0.05
Storage	0.01	0.05
Distribution	-	0.10
Total	0.37	1.3

Flow Diagram 29 - Waste Coefficients-Ice Cream Subprocess-Stick Novelties

Plant Process	Pound Waste Water/ Pound Milk Processed	Pound BOD/1000 Pounds Milk Processed
From ice cream freezer	0.15	0.30
Extruded onto conveyor	0.05	0.10
Hardening tunnel, dipping in coatings	-	0.10
Bagging, boxing, overwrap	-	0.05
Extrusion, slice machine or ice cream sandwich machine	0.05	0.10
Wrapping, boxing, overwrap	-	0.05
Hardening	0.10	0.10
Decorating	0.05	0.15
Storage	0.01	-
Distribution	-	-
Total	0.46	0.95

Flow Diagram 30 - Waste Coefficients-Ice Cream-Subprocess Stickless Novelties



Plant Process	Pound Waste Water/ Pound Milk Processed	Pound BOD/1000 Pounds Milk Processed
Milk receiving	0.125	0.2
Storage standardization	0.015	0.18
HTST or UHT, pasteurization homogenization	0.50	0.80
Vacuum evaporation	9.0	0.25
Storage	0.125	0.30
Can filling conveying	0.10	0.10
Cooking and sterilizing	0.30	0.05
Casing	0.05	-
Tank truck transfer (fluid)	0.15	0.30
Distribution	-	-
Total	11.5	1.88

Flow Diagram 31 - Waste Coefficients-Condensed Milk Process

Plant Process	Pound Waste Water/ Pound Milk Processed	Pound BOD/1000 Pounds Milk Processed
Condensed milk from storage	0.125	0.30
Spray drying	0.05	0.20
Screening and blending	0.01	0.10
Instantizing	0.20	0.10
Tablet making	-	0.10
Container filling and packaging	0.05	0.10
Storage	0.01	0.05
Distribution	-	-
Total	0.44	1.25

Flow Diagram 32 - Waste Coefficients-Spray Drying Process

Table 49 - BOD Coefficients for Cottage Cheese Operations*

Operation	ppm BOD		Lb BOD/1000 Lb		Lb BOD/1000 Lb Milk Processed	
	A	B	A	B	A	B
Whey, Cottage Cheese	3,700	35,000	37	35.0	26.6	25.2
First wash	17,000	11,700	17	11.7	5.8	6.3
Second wash	1,700	2,200	1.7	2.2	1.3	1.2
Third wash	2,000	550	0.4	0.55	0.7	0.30
Fourth wash	2,200	--	0.44	--	0.75	--
Transferring and Filling**	--	185,000	--	185.0	--	0.027

*Operation A used three washings, each wash being equal to 75% of whey volume. Operation B used four washes, with the first, third and fourth washes being equal to 50% of the whey volume and the second wash being equal to the whey volume.

**Values based on curd spillage. Usual amount of curd loss would range from 5-10 pounds/100 pounds of cottage cheese.

Table 50 - BOD Coefficients for Whey and Wash Water
from Cottage Cheese Manufacture

Operation	Volume as Percent of Whey	Percent Solids in Whey		Percent Fines		BOD of Whey/ 1000 pound Wash Water Ave.	BOD of Whey ppm, Ave.	BOD of Fines, Ave.
		Range	Ave.	Range	Ave.			
Whey	100%	6.47-6.77	6.61	0.13-0.20	0.16	44.8	44,800	1.6
1st wash	75	1.23-4.22	3.24	0.04-0.21	0.11	21.3	21,300	1.1
2nd wash	75	0.48-1.18	1.21	0.04-0.37	0.13	2.46	4600	1.3
3rd wash	75	0.16-0.33	0.26	0.0 -0.2	0.01	3.2	3200	0.01

The care taken in manufacture to avoid curd breakage is significant in respect to control of the BOD in the waste water. Consideration needs to be given to the possibility of developing cheese making processes which would basically eliminate whey or minimize it by using concentrated milk as a starting material or the development of an entirely new process based on dry milk solids.

Role of Condensate in Cooling Waters

Cooling waters not coming in contact with milk are not polluted unless leaks or spillage occur. Condensate waters from evaporating equipment, except for boil-overs, have a very low BOD content and such waters are suitable for direct discharge to stream without treatment or for recycle utilization in other parts of theplant. The BOD strength of such condensates are usually lower than an effluent resulting from the treatment of concentrated milk wastes. Consideration should be given to the installation of automatic liquid level controls, entrainment separators and other devices in milk evaporating equipment to prevent boil-overs and loss of product, rather than to provide treatment for such wastes. Zack (1286) compared the BOD in condensate waters where controls were used and where boil-overs and other losses were known to have occurred. His data are summarized in Table 51.

Table 51 - BOD in Condensate Waste Waters

Plant	Parts per Million		Pounds/1000 Pounds Milk Handled	
	Low Milk Losses	High Milk Losses	Low Milk Losses	High Milk Losses
1	27.0	46.0	0.20	0.51
2	2.5	82.0	0.02	1.48
3	6.0	--	0.15	--

Rinses: An identifiable source of BOD in dairy plant wastes, and one which may be reduced materially, is the product left in lines, tanks, and processing equipment after the product had been removed.

The amount of product remaining in a line or processing equipment depends upon the design of the equipment to insure draining, the allowance of adequate time for draining, and the type of product in the equipment. There is no information available in literature concerning the amount of product remaining on equipment other than milk, so a laboratory experiment was conducted to obtain information on the losses of various fluid dairy products of different viscosities. These values are presented in Table 52. The relationship of the percentage product remaining to product viscosity is shown in Figure 28.

Table 52 - Effect of Product Composition on Residual Solids Left On Processing Equipment Surfaces*

Product	Viscosity, cp	% Remaining on Surface	Pounds BOD_5/1000 Pounds Product
Milk, skim	1.4	0.10	0.072
Milk, whole	2.0	0.26	0.26
Chocolate milk	21.0	0.47	0.69
Half-and-half	15.6	0.39	0.61
Cream, 18% fat	45	0.73	1.5
Cream, 40% fat	91	0.95	3.8
Cultured buttermilk	500	2.3	1.47
Sour cream	9000	3.5	7.0
Ice-cream mix	121	0.86	3.4

*Values obtained following two minutes of draining. Analyses made at 20°C.

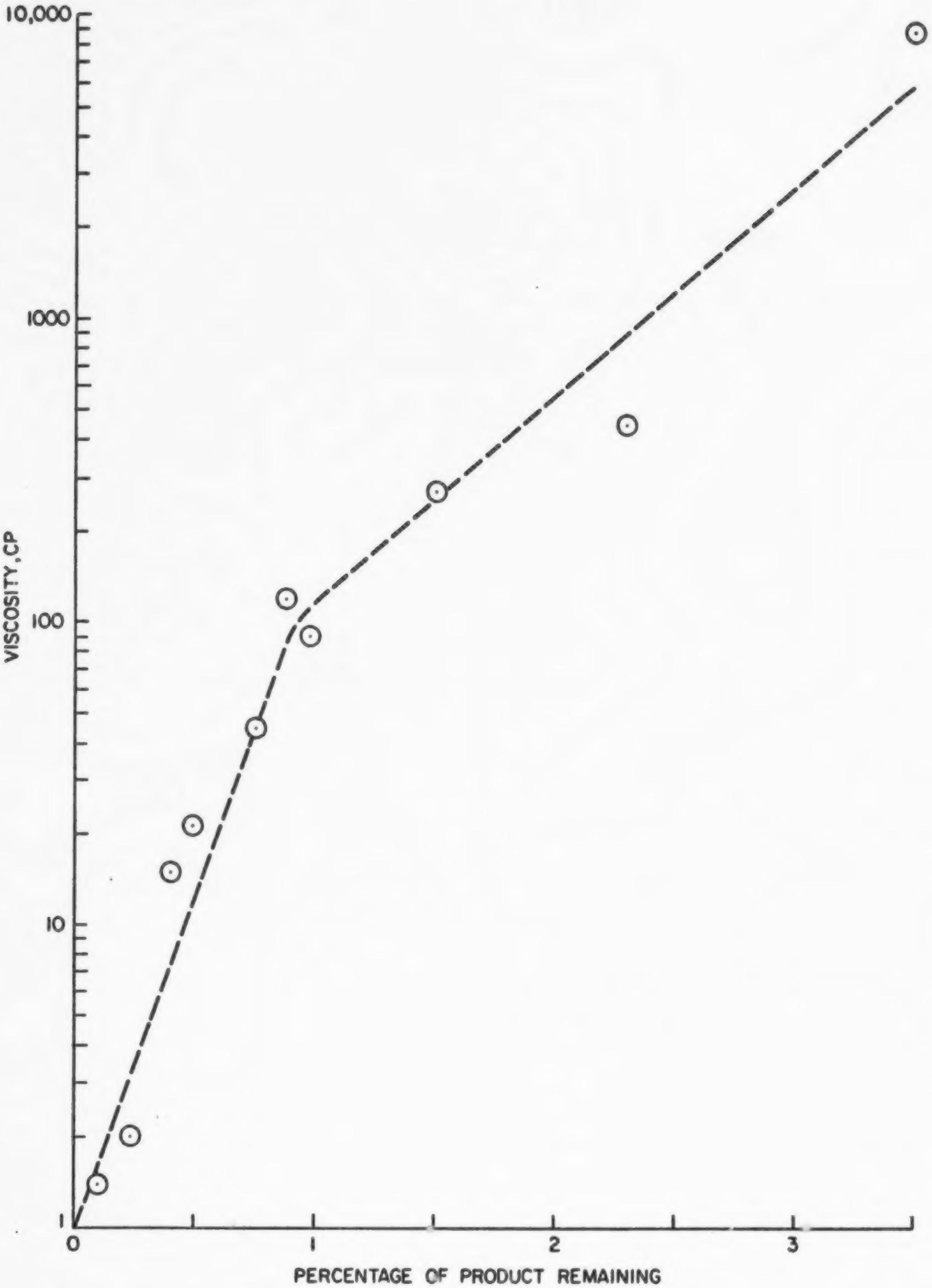


Figure 28 - Effect of viscosity on percentage of product remaining on equipment surfaces after two minutes draining

The volume of milk remaining in a 10-gallon can after drainage for various periods is shown below:

Period of Draining (seconds)	Percent of Product Remaining	Pound BOD/1000 Pound Milk	Accumulated BOD
10	0.20	0.2	0.2
23	0.14	0.14	0.34
30	0.13	0.13	0.47
60	0.09	0.09	0.56
90	0.06	0.06	0.61

The BOD coefficient after 10 seconds draining is about the same as reported for tank and tank truck cleaning. The effect of the method of feeding 10-gallon cans to the can washer on product losses are shown in Table 53.

Table 53 - Effect on Milk Losses of Methods of Feeding Cans to Washer (1,000 10-gal cans)

Disposition of Milk	Fed Improperly		Fed Properly	
	Milk	% of Total	Milk	% of Total
Into weigh can	70,100	99.424	70,617	99.690
Recovered by natural drainage	337	0.478	158	0.223
Unrecovered, left in cans	69	0.098	62	0.087
Total contained in cans	70,506	100.000	70,837	100.000
Milk recovered: per can	0.337	--	0.158	--
BOD_5/1000 lb. milk received	0.48	--	0.23	--

Illustrative data for rinse water volume and fat content of rinses for different types of equipment is shown in Table 54.

Table 54 - Volume and Fat Content of Rinse Waters from Various Types of Dairy Food Plant Equipment

Plant Equipment	Rinse Water, Pound	Butter-fat, Percent	Recoverable Fat, Pound/100 pound
Storage tank -- 3,000 gal.	120	1.20	1.4
Storage tank -- 6,000 gal.	170	2.30	3.9
Homogenizer	62	2.05	1.3
Cooler and connecting pipe	100	1.20	1.2
Product lines	68	2.20	1.5
Cream vat -- 600 gal.	80	2.75	2.2

Detergents and Sanitizers: The volume and concentration of sanitizers utilized in the sanitation of dairy plant equipment by non-recycle systems are shown in Table 55.

Table 55 - Sanitizer Utilization in the Sanitation of Dairy Food Plant Equipment

Process	Pounds Sanitizing Solution/1000 Pounds Milk Processed	ppm Sanitizer Required
Tank trucks	0.16	50
Storage tanks (20,000 gal.) lines	0.006	50
HTST Pasteurizer	0.0005	50
Fillers	0.001	100

Since cleaners and sanitizers appear to have an effect on the refractory material in dairy plant wastes and contribute materially to COD and, to a lesser extent, BOD, information is needed in respect to the volume and concentration of materials utilized. A comparison between the concentration and volume for recycle and non-recycle treated systems for two fluid milk and cottage cheese plants of the same size is shown in Table 56. The systems are essentially equal in volume used, whereas the recycle system used 35% more cleaning compound to achieve equivalent cleaning efficiency.

Table 56 - Comparison of Cleaning Compound and Cleaning Solution Usage in Recycle CIP Systems in Two Fluid Milk-Cottage Cheese Plants of the Same Size*

Plant	Volume Milk Processed	Pounds of Cleaning Compounds Used/Day	Gallons of Cleaning Solution/Day	Average Percent Concentration of Cleaning Solution
A	530,000 lb	699	18,000	0.4
B	500,000 lb	515	21,000	0.2

*Plant A used a recycle cleaning system, recharging six CIP or COP tanks twice a day to accomplish efficient cleaning; Plant B Used the "once-through" or nonrecycle system of cleaning with two centralized CIP tanks and two COP tanks.

IN-PLANT CONTROL OF DAIRY PLANT WASTES

A prevalent view within the dairy industry has been that the elimination of whey from dairy plant waste waters would essentially solve the problem of fluid pollution for the dairy industry. Site visitations and information on waste coefficients obtained from industry would indicate that the elimination of whey does not necessarily solve the pollution problem. In plants handling cottage cheese, where whey was excluded from the waste water, BOD coefficients ranged from 0.7 to 9.6. The controlling factor in respect to in-plant control of dairy plant wastes appears to be management's attitude and the ability of middle management to properly supervise plant operations.

Comparison of Plant Reported Wastes with Wastes Calculated from BOD_5 Values

All dairy plants maintain records of incoming and outgoing milk and milk products and calculate a percentage of fat and nonfat solids loss on a monthly basis. The industry has frequently used these figures to predict the BOD values in the dairy food industries waste water. Where data was available from industry, reported losses were used to calculate probable BOD from milk solids sources and the reported BOD was used to back-calculate the percentage loss of whole milk from BOD going to sewer. In all cases the assumption was made that 10.0% of the BOD was derived from non-milk solids origin, based on actual data from two plants. Thus 1.0 pound of BOD was converted to 9.0 pounds of 3.5% milk. The data are presented in Table 57. With the exception of plants 1 and 48, the

Table 57 - Comparison of Reported and Calculated Milk Solids Losses

Plant No.	% Plant Loss Reported		Calculated BOD (lb) from Reported Loss	Reported Lb. BOD	% Loss of Whole Milk from Reported BOD
	% Nonfat Solids	% Fat			
1	0.35	0.38	188	139.20	0.278
2	0.68	1.28	1210	2401.20	2.030
3	0.14	0.83	450	1102.0	2.030
4	0.02	1.10	497	2818.80	6.264
6	--	1.0	805	1450.00	1.740
7	1.0	1.0	801	1763.20	2.204
9	0.16	0.14	5	747.04	9.960
10	0.5	0.5	543	3526.40	3.248
11	0.7	0.5	129	945.40	3.712
12	0.6	0.7	156	1067.20	4.756
18	0.87	0.60	156	963.96	3.596
20	1.0	1.25	500	3.633	9.048
21	1.0	0.8	429	1943.00	3.596
23	0.4	0.4	78	1811.92	9.280
24	0.5	0.5	34	135.72	1.740
25	0.09	0.09	4	83.52	1.856
26	1.4	1.5	33	634.52	28.884
28	--	0.35	169	1038.20	2.088
29	0.45	0.35	64.3	380.48	1.740
30	0.75	0.47	486	7115.44	6.844
34	1.0	1.4	1232	7900	8.9
36	1.1	1.1	33	55	1.8
37	0.8	1.0	666	47,000	7.06
42	1.0	0.9	128	1120	7.83
48	0.75	0.8	200	165	0.696

calculated losses exceeded the reported loss, with this difference ranging from 1.6 to 20 times the reported loss. Because of the compensating errors in the plant reported losses, such as sampling and testing errors, under-filling packages, etc., the reported losses do not accurately reflect the actual milk solid loss to sewer for most dairy plant operations. The high values back-calculated from BOD appear to be real. Thus evidence is presented of the potential profitability of waste control and the value of accurate BOD and compositional analysis of dairy food plant waste waters as a quality control tool in reducing fat and solids losses in plant operations.

MANAGEMENT QUALITY AND WASTE COEFFICIENTS

In the course of the study on the State of the Art of Dairy Wastes and Dairy Waste Treatment, site visitations were made to 20 dairy plants for which waste coefficient data were available. It was possible to obtain an evaluation of management practices in some of the other plants for which waste coefficient data also were obtained.

In evaluating management practices, the following criteria were utilized:

1. Housekeeping practices.
2. Water control practices; frequency with which hoses and other sources of water were left running when not in actual use.
3. Degree of supervision of operations contributing to either volume or BOD coefficients.
4. Extent of spillage, pipe-line leaks, valve leaks and pump-seal leaks.
5. Extent of carton breakage and product damage in casing, stacking and cooler operations.
6. Practices utilized in handling whey.
7. Practices utilized in handling spilled curd particles during cottage cheese transfer and/or filling operations.
8. Utilization of practices to reduce the amount of wash water from cottage cheese or butter operations.
9. Extent to which the plant is utilizing procedures to segregate and recover milk solids in the form of rinses and/or products from pasteurization start-up and product change-over.

10. The procedures utilized in handling returned products.

11. Evaluation of the management attitude toward waste control.

Although the evaluations are subjective in nature and do not lend themselves to absolute quantitation, they do provide a valid impression of management over-all quality of practices in respect to waste control.

The influence of management practices affecting waste coefficients, volume and BOD coefficients is summarized in Table 58. Evaluation of the information provides a recognition that there is a direct relationship between the quality of management practices in respect to waste control and the waste coefficient. Under good control, both volume and BOD coefficients are low. Based on observations obtained during the investigation, waste volume or BOD levels below one pound/pound and one pound/1000 pounds, respectively, would be expected if management were conscientiously carrying out good practices. Under poor management, both BOD and volume coefficients are high. Usually values greater than three pounds of waste water per pound of milk or three pounds of BOD per thousands pounds of milk reflect poor management practices. Some evidence revealed where there is good control of BOD and poor control of waste water volume and vice versa.

Control of waste coefficients in a dairy plant can take several pathways. The first includes those changes that can be put into operation without additional expense. The second group are the engineering changes that can affect material reduction in either waste water volume or BOD.

GOOD MANAGEMENT PRACTICES IN WASTE CONTROL

The value of good management practices in waste prevention was recognized early by Trebler and Harding (1136) and by many other investigators (265, 338, 363, 590). Practices were recommended in the early waste guides for the dairy industry and repeated as they were up-dated from time to time. Suggestions for prevention of dairy waste include:

1. The adoption of a definite waste prevention program and an educational program to insure that all plant personnel are waste-prevention conscious.

2. Utilization of waste prevention committees in plants and within companies to evaluate the type of jobs and to make recommendations. Such committees should have sufficient authority to invoke change.

Table 58 - The Effect of Management Practices on Waste Coefficients

Plant No.	Products Manufactured	Milk Processed Lb/Day	Lb BOD/1000 Lb Milk Processed	Lb Waste Water/ Lb Milk Processed	Level of Management Practices	Explanation of Practices
1	Milk	400,000	0.3	0.4	Excellent	Rinses saved, hoses off, out of use, filler drip pans
42	Milk	150,000	7.8	5.2	Poor	No steps taken to reduce waste
43	Milk	500,000	0.2	0.1	Excellent	Rinses saved, returns excluded, filler drip pans, cooling tower
6	Cottage Cheese	600,000	2.0	0.8	Good	Whey excluded, fines screened out, wash water to drain
36	Cottage Cheese	300,000	1.3	4.7	Good	Whey excluded, spilled curd handled as solid waste
37	Cottage Cheese	650,000	71	12.4	Poor	Whey included
9	Ice Cream	17,000	32.2	5.3	Poor	Rinses to drain leaks, drips; water running-not in use
26	Ice Cream	34,000	2.1	0.8	Good	Freezer rinses segregated
48	Milk	250,000	0.7	1.0	Good	Whey & wash water excluded, rinses segregated, returns to feed use
8	Milk, Cottage Cheese	1,000,000	8.6	2.0	Poor	Whey excluded; many drips, leaks, returns included
10	Milk, Cottage Cheese	900,000	3.3	1.1	Fair	Whey excluded, good water volume control

Table 58 (Continued)

Plant No.	Products Manufactured	Milk Processed Lb/Day	Lb BOD/1000 Lb Milk Processed	Lb Waste Water/ Lb Milk Processed	Level of Management Practices	Explanation of Practices
40	Milk, Cottage Cheese	1,000,000	4.12	1.2	Good	Whey included, rinses saved
52	Milk, Cottage Cheese	465,000	1.8	1.1	Good	Returns excluded, good water control
3	Milk Ice Cream Cottage Cheese	400,000	3.9	1.4	Fair	Whey & wash water excluded, rinses excluded
30	Milk Ice Cream Cottage Cheese	800,000	7.7	3.5	Poor to fair	Whey excluded, sloppy operations, spillage, leaks, hoses running
33	Milk Ice Cream Cottage Cheese	600,000	12.9	3.3	Poor	Whey included
34	Milk Ice Cream Cottage Cheese	900,000	9.1	2.8	Poor	Whey excluded, many leaks, drips, etc.
44	Milk, Butter	300,000	0.87	0.8	Good	Buttermilk excluded, few leaks, dry floor conditions
50	Whey powder	500,000	0.2	5.9	Good-fair	No entrainment losses, all powder handled as solid waste, no leaks or drips
56	Milk powder, Butter	200,000	3.0	2.5	Fair	Continuous churn, hoses running, numerous leaks and drips

3. Instruction of plant personnel completely in respect to proper operation and handling of all dairy plant processing equipment. Major losses are due to poorly maintained equipment and to negligence of inadequately trained and insufficiently supervised personnel.

4. Make a study of the plant and develop a material balance to determine where losses occur and take steps to modify and replace unsatisfactory equipment. Where improper maintenance is the cause of losses, a specific maintenance program could be instigated and maintained.

5. Adequate equipment for receiving, cooling, storing, processing of milk, to take care of the maximum volume of plush production and special products should be insured. All piping, around storage tanks and other areas, should be identified to eliminate mis-assembly and damage of parts and subsequent leakage.

6. Accurate temperature control should be provided on plate, tubular and surface coolers to prevent freeze-on, which may result in loss of products.

7. Eliminate valves on outlet side of internal tubular or plate heaters and coolers and maintain plates and gaskets in good repair to eliminate waste due to blown or broken gaskets.

8. Install suitable liquid level controls with automatic pump stops, alarms, and other devices at all points where overflows could occur; such as storage tanks, processing tanks, filler bowls and CIP and COP tanks.

9. Maintain vats, tanks, and pipelines in good condition to eliminate and reduce to a minimum leaky joints, gaskets, packing glands and rotary seals.

10. See that vats and tanks are properly designed and installed high enough from the floor for easy draining and rinsing if they are hand cleaned. Tanks should be pitched to insure draining.

11. Pipelines should be installed so that they are properly supported to eliminate vibration-induced leaking joints (where welded lines are not used or points in welded lines where CIP gaskets are utilized) and to insure that the lines are properly pitched to insure draining of the lines.

12. Make sure the correct connections are made on plate type heat exchangers so that there is no possibility of milk being pumped into the water side of the exchanger or water being pumped into the milk side.

13. Provide and use proper drip shields on surface coolers and fillers so that no product can reach the floor. Avoid overfilling cheese vats, ice cream mix vats, vat processors or cooling tanks so that no spillage occurs during product agitation. The liquid level in cheese vats should be at least three inches below the top edge of the vat.

14. Repair or replace all worn out and obsolete equipment and/or parts of equipment including sanitary valves, fittings and pumps. To the extent possible, drips and leaks occurring during the processing run should be collected in containers and not allowed to go down floor drains.

15. Avoid foaming of all fluid dairy products, since foam readily runs over processing vats and other supply bowls and contains large amounts of solids and BOD. Utilization of air tight separators, proper seals on pumps and proper line connections to avoid incorporation of air when lines are under partial vacuum will avoid foam.

16. Where canned milk is still received, use grid style (western style) dumping of milk cans.

17. Where cans are still in use, leaky milk cans should be replaced or repaired.

18. All cases, conveyors, and stackers should be maintained in proper operating condition to avoid jamming and subsequent loss of product from spillage and/or broken packages.

19. When unloading tank trucks, special care should be taken to prevent spillage from the sanitary pipe or hose connection. Tanks should be completely drained before disconnecting the sanitary pipe or hose. Tank trucks should not be permitted to stand for more than an hour, if possible, to avoid creaming and excessive loss of product in rinsing and cleaning of the tanks subsequently. Once creaming occurs, even excessive agitation will not prevent the adherence of the cream material at the side of the tank.

20. Where can receiving is still in use, an adequate drip saver between can dumping and can washing should be provided. Small product-saving pre-rinse (three to four ounces per can) should be used at the end of the can washer over the drip-pan saver, extending for two to three drain positions. Milk obtained from drips pre-rinsings should be utilized for animal feed. For tank trucks, this portion of rinses can also be collected and saved for feed or food purposes.

21. Water hoses should be turned off when not in use. Hoses equipped with automatic shut-off valves should be utilized to avoid excessive water usage.

22. Every effort should be made to eliminate all spillages rather than relying on the hose to wash the whey after spillage occurred.

23. Where possible, hot wells should not be utilized for preheating products. Plate, tubular or surface feeders should be used. Where hot wells are utilized, care must be taken to avoid overfilling and to preventing boiling over. Application of liquid level controls to hot wells will help avoid excessive product loss.

24. Eliminating product loss from heat-cracked bottles where bottle fillers are utilized, and in collers, by properly maintaining temperatures of tanks, sprays and bottle washers as specified by the manufacturer.

25. All bottles should be inspected carefully at the beginning of bottle washing, so that defective bottles do not get to the fillers, and thus avoid product losses.

26. For plastic and glass bottles fillers, capers should be maintained in first class condition to avoid breakage and product loss. Similarly, paper filling machines should be maintained in order to avoid jams and product spillage. Fillers should be equipped with drip shields and the spills collected to avoid product going to drain.

27. Filler valves should be checked to see that all containers are filled to correct capacity at the temperature filling. In glass bottles, filling to the cap seat may create spillage when the milk warms up by the cap being forced past the cap seat.

29. Bottles and paper containers should be handled carefully during casing, stacking, loading and delivery to avoid product losses to drain.

30. Evaporators should be operated at a sufficiently low liquid level to prevent boiling over of the product.

31. All external tube chest evaporators should be designed with a tangential inlet from the tube chest to the evaporating space. All coil or calandria evaporators should be equipped with efficient entrainment separators. "Splash disks" on top of the evaporators will not avoid entrainment loss unless operated carefully under rated capacity with low liquid level and with low vapor velocity.

32. Condensors of evaporators should be equipped, wherever possible, with a full barometric leg to eliminate the possibility of sucking water back to the condensor in the evaporator in case of pump or power failure. Full barometric legs will also be useful in maintaining a constant volume which will assist in reducing entrainment losses.

33. Care needs to be taken in materials handling to avoid spillage of cased, canned or barreled dairy products and product ingredients.

34. Where sweetened, whole or condensed skim milk or ice cream mix is manufactured, care needs to be taken so that sugar or dry ingredients are not spilled on the floor and washed into the sewer. Any spillage of dry ingredients should be swept up rather than washed down.

35. Care needs to be utilized to avoid incorporation of cleaning compounds and/or sanitizing solutions into milk products and thus creating excessive material for disposal.

36. All spilled or wasted products from roller dryers and/or spray dryers should be swept and scraped up to be disposed of for animal feed and not washed to drain.

37. Whey collection systems should be soundly engineered free of all leaks from lines, valves, fittings and tops. As little as 10% whey solids can cause a major upset in the efficiency of the biological treatment facilities.

38. Stand-by pumps should be provided for all processes so that it is not necessary to dump whey and/or other by-products in case of breakdown of regular pumps or power failure. Whey, and where possible cottage cheese wash

water, should be excluded from the sewer. Whey wash water may be spray irrigated in most areas where land is available. All whey should be utilized for food or feed purposes.

39. All spilled cheese particles from cheese operations, fruits and nuts from ice cream operations, should be swept up and not washed down the sewer drains.

40. All whey should be drained from cheese and segregated. Small volume (5-10%) of a pre-rinse or use of whey for cooling cottage cheese curd will reduce BOD of wash water.

41. Adequate wiers and continuous sampling equipment should be provided at the outlet of all dairy plants for monitoring wastes, strengths and volume.

42. Eliminate steam-water mixing T's for making hot water and utilize regular hot water systems to permit use of shut-off valves at the end of hose lines. This can result in a 40 to 60% reduction of waste water volume.

43. Thoroughly drain all lines, tanks and processing vats before rinsing. Rinse before product dries on surface.

REDUCTION IN WASTES THROUGH PROPER DESIGN AND UTILIZATION OF ENGINEERING PROCESSES

As new plants are built or remodeled and more and more plants incorporate CIP and process automation capabilities, the proper application of design of plants and process can afford material reduction in waste loads. The theoretical effect of advanced technology on reduction of waste loads is well illustrated in Waste Profile No. 9 (355), even though such reduction had not, in fact, occurred in real practice within the industry at the present time. Indeed, in some cases, utilization of automation and mechanization had increased the BOD coefficients. Part of this increased waste relates back to the fact that large complex plants are more difficult to manage and, to certain inherent characteristics of mechanization automation which increase waste loads. Some of these include:

1. Utilization of chain and belt conveyors requires the utilization of relatively high quantities of lubricants which are high BOD containing materials.

2. Incorporation of casers, case stackers and conveyors increase spillage and loss of product to drain in relatively large volumes because of the dumping in entire cases or case stacks if the equipment is not continuously maintained in good operating condition.

3. Utilization of high capacity equipment up to 100,000 pounds per hour. In the case of pasteurizers, the start-up, shut-down or product changeover of a pasteurizing unit operating 100,000 pounds an hour will cause product loss of about 1700 pounds (170 pound BOD/minute) diverted to drain.

4. CIP separators which shoot sludge to the sewer every thirty minutes have increased the waste load. With hand-cleaned separators, it was possible to scrape out the sludge and handle it as a solid waste.

5. The product lines in large capacity plants that are CIP cleaned hold from 0.8 to 1.2% of the total milk received. Proper design of piping systems, maximum utilization of gravity draining, adequate time for draining product before initiating the washing cycle, and proper designed air blow-down are essential to avoid excessive losses.

Some plants have made material reduction in their waste coefficients (such as Plant No. 1, handling milk with a BOD and volume coefficient of less than 0.5, respectively) through utilization of the capabilities of their automated processing and CIP system to effect material reductions in normal waste loads. An illustration of difference by unit processes between a standard plant and a plant exercising loss control has been presented previously.

Engineered Reduction of Losses from High Volume HTST Pasteurizing Units

The industry recognizes that HTST units must be started, and stopped on water. The problem of start-up and changing from water to product, and back to water, constitutes the major source of losses to drain in the pasteurization process. In starting up the operation the balance tank, the pasteurizer generally operates at a volume level of about 60 gallons of product, which normally in start-up becomes a mixture of water and product which must be disposed of -- generally down the drain. Most plants start and stop pasteurizing units two and three times a day and frequently use water between product change-over. Conservatively figuring six such changes a day, approximately 150 pounds of BOD would be generated. Through utilization of a recycle system (Figs 29-31), material reduction in losses can be achieved. The recycle system is identified at different stages of product change-over and provides procedure for automatic time separation of water from product start-up,

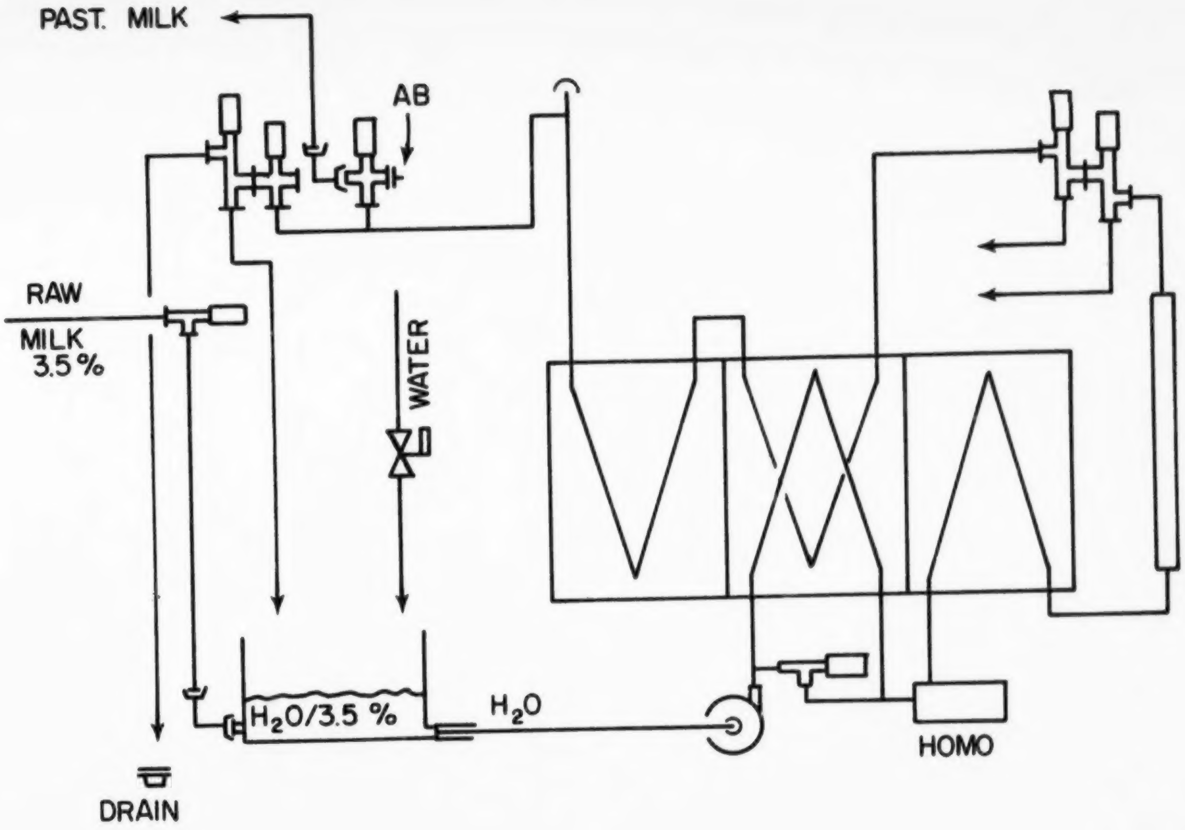

PAST. MILK
AB
RAW
MILK
3.5%
WATER
DRAIN
$H_2O/3.5$ %
H_2O
HOMO

Figure 29 - Pasteurization recycle system, initiation of water to product separation

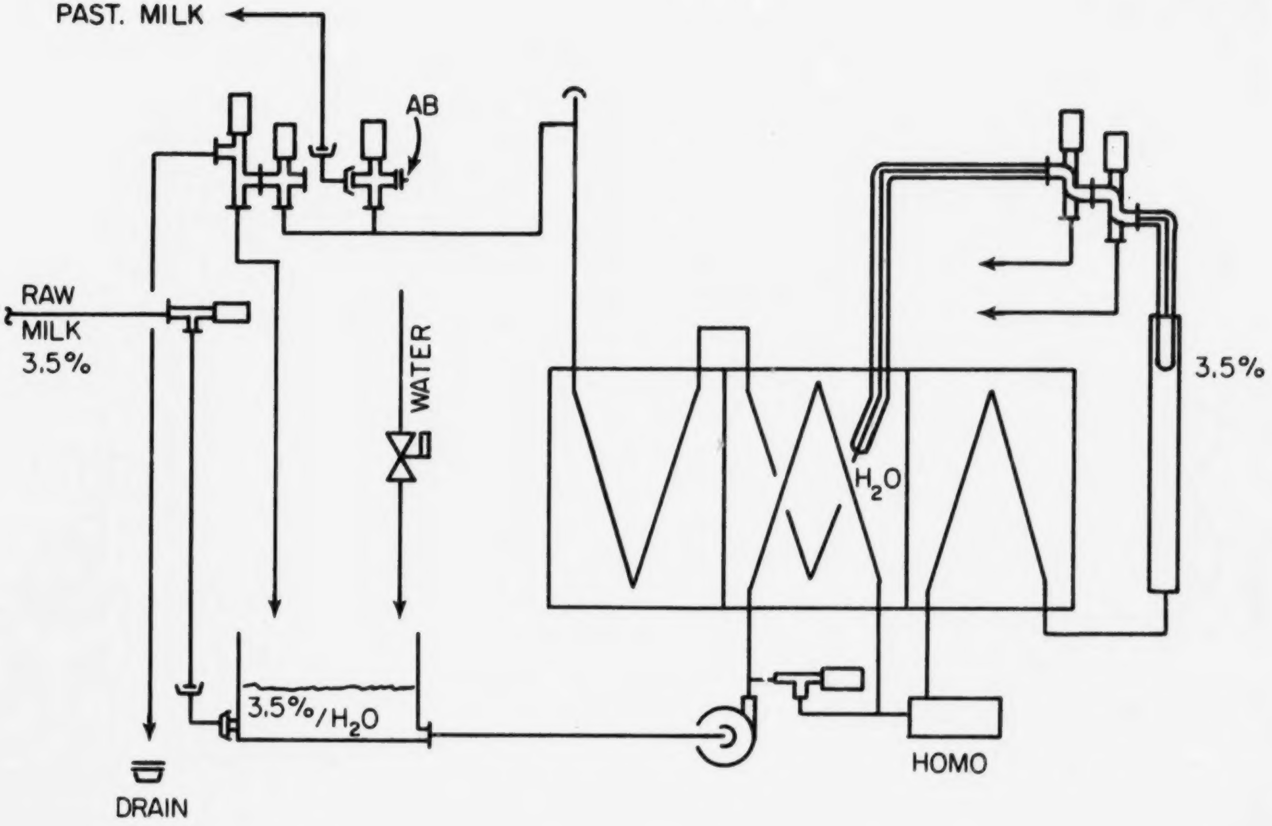

PAST. MILK
AB
RAW
MILK
3.5%
WATER
$3.5\%/H_2O$
DRAIN
H_2O
HOMO
3.5%

Figure 30 - Pasteurization recycle system, half-way through separation

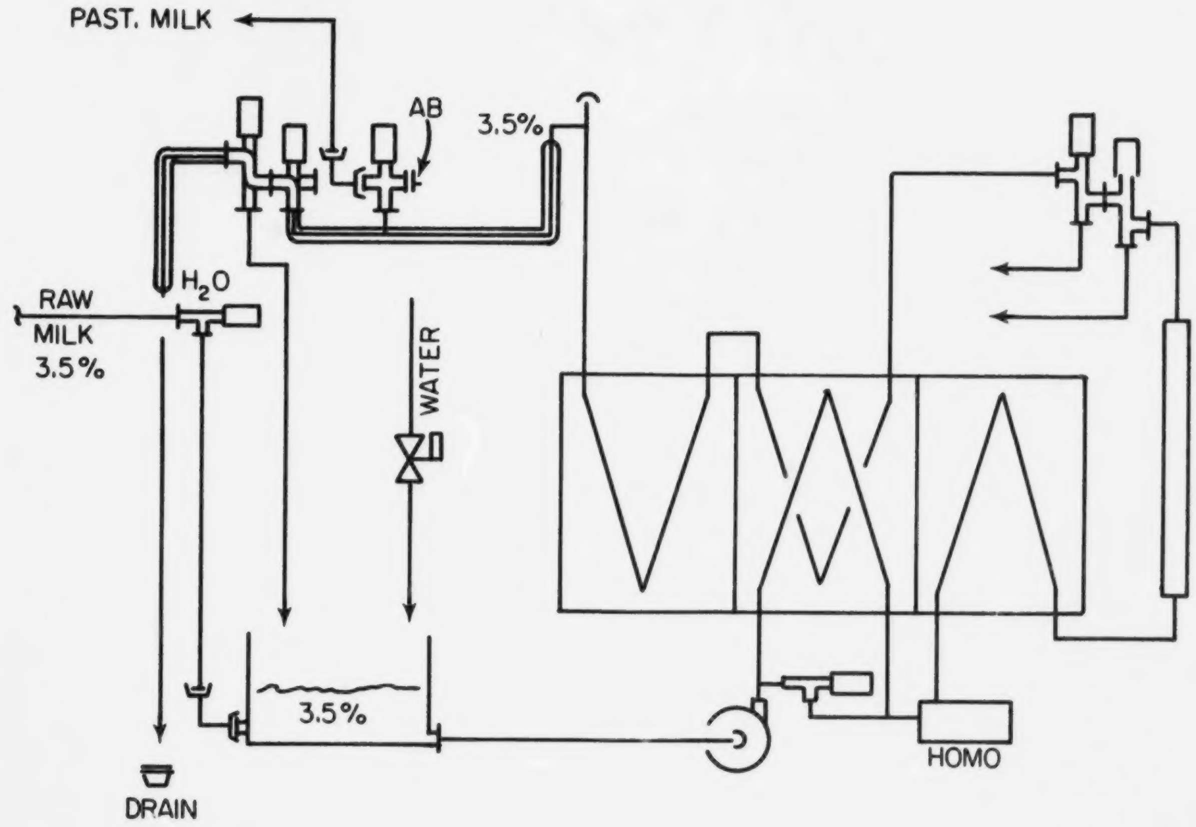

PAST. MILK
AB
3.5%
H_2O
RAW
MILK
3.5%
WATER
3.5%
DRAIN
HOMO

Figure 31 - Pasteurization recycle system, nearing change in recycle valve

automatic time separation of product from water at shut-down and automatic time separation of one product from another product during the operating day. Through proper design of the balance tank to provide a pod-type outlet and incorporation of the recycle control system, the volume in the tank at point of changeover can be reduced from 60 to 15 gallons. The rate of change in fat content going from water to milk is shown in Figures 32 and 33. Figure 34 shows the start-up and shut-down operation going to water to milk in a typical system operating at a thousand pounds per minute (60,000 lb. per hour). At the mid-point of a product separation we have approximately 1000 pounds of water-milk mixture at a 1.5% fat test (44 lbs. of BOD). Separation of the first minutes operation and collection of this in tanks for utilization as a source of material to be mixed with other solids for utilization in other food products can materially reduce the waste load. In HTST operations, this would result in a 44% reduction of BOD from the pasteurization process. Assuming the BOD coefficient of pasteurization to be 0.8, the utilization of an engineered recycle and segregation system can reduce this coefficient to 0.45, which is about the value reported for two plants utilizing the recycle system.

Dairy food plant automation systems can be utilized similarly in recovering rinses from tankers, tank trucks and lines and collecting these for product use as well. In one operation, the rinsing 6000-gallon tank trucks utilized 250 gallons of water for a single rinse, resulting in approximately 9.0 pounds of BOD in 250 gallons of water per tank truck. By changing the three burst-rinses, segregating and saving the first 30-gallon rinse, 80% of approximately 7-1/2 pounds of BOD was eliminated from the sewer per tank truck. This rinse contained 1.5% fat which reduced the receiving coefficient to 0.05. This fat content of rinses raise to 3.4% fat for high solids products or for rinses from tank trucks that have remained stationary for more than one hour before being emptied.

Reduction of Loss Through Continuous Processing

The utilization of the centrifugal machine in the form of a clarifier-separator can be utilized in combination with high-temperature short-time systems to accomplish a variety of processing operations in a simple and straightforward manner to eliminate the necessity to utilize processing vats for the make-up of skim milk, low-fat milk, fortified milk, half-and-half, creams and other by-products. Utilization of positive displacement pumps may serve as a means of (a) providing for improved control of fat test and, (b) insuring the movement of cream to the cooling equipment in the tanks and vats at various distances without danger of loss of product through the separator plugging. The combined system could be utilized on a continuous and automated basis to make a variety of fluid milk products.

Milk can be metered to the constant level tank (Fig. 34) as may cream, condensed skim, or plain skim condensed, and in this manner a variety of products can be produced through "on-the-run" batch blending. By initiating flow into a given surge tank while still on homogenized

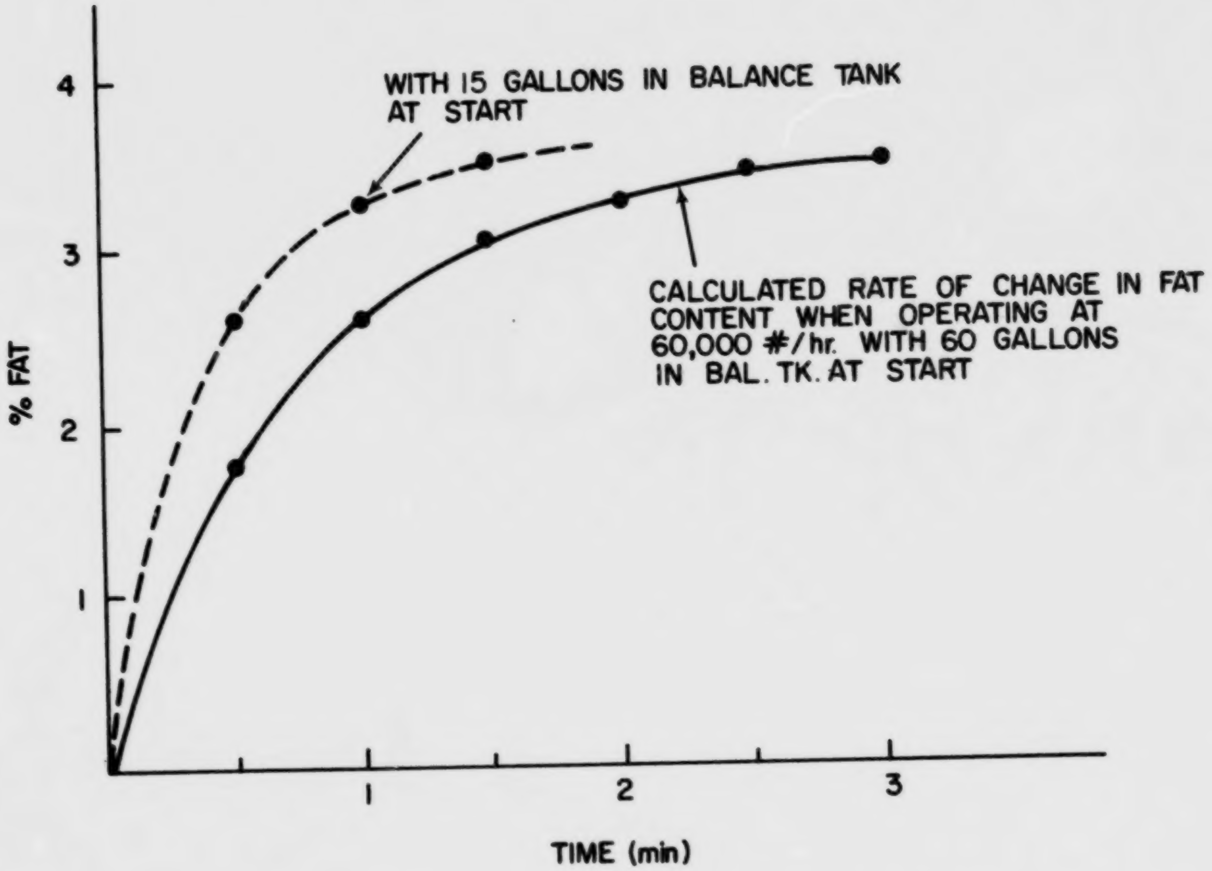


Figure 32 - Effect of time after change from water to milk on fat content of waste water going to drain during pasteurization start-up

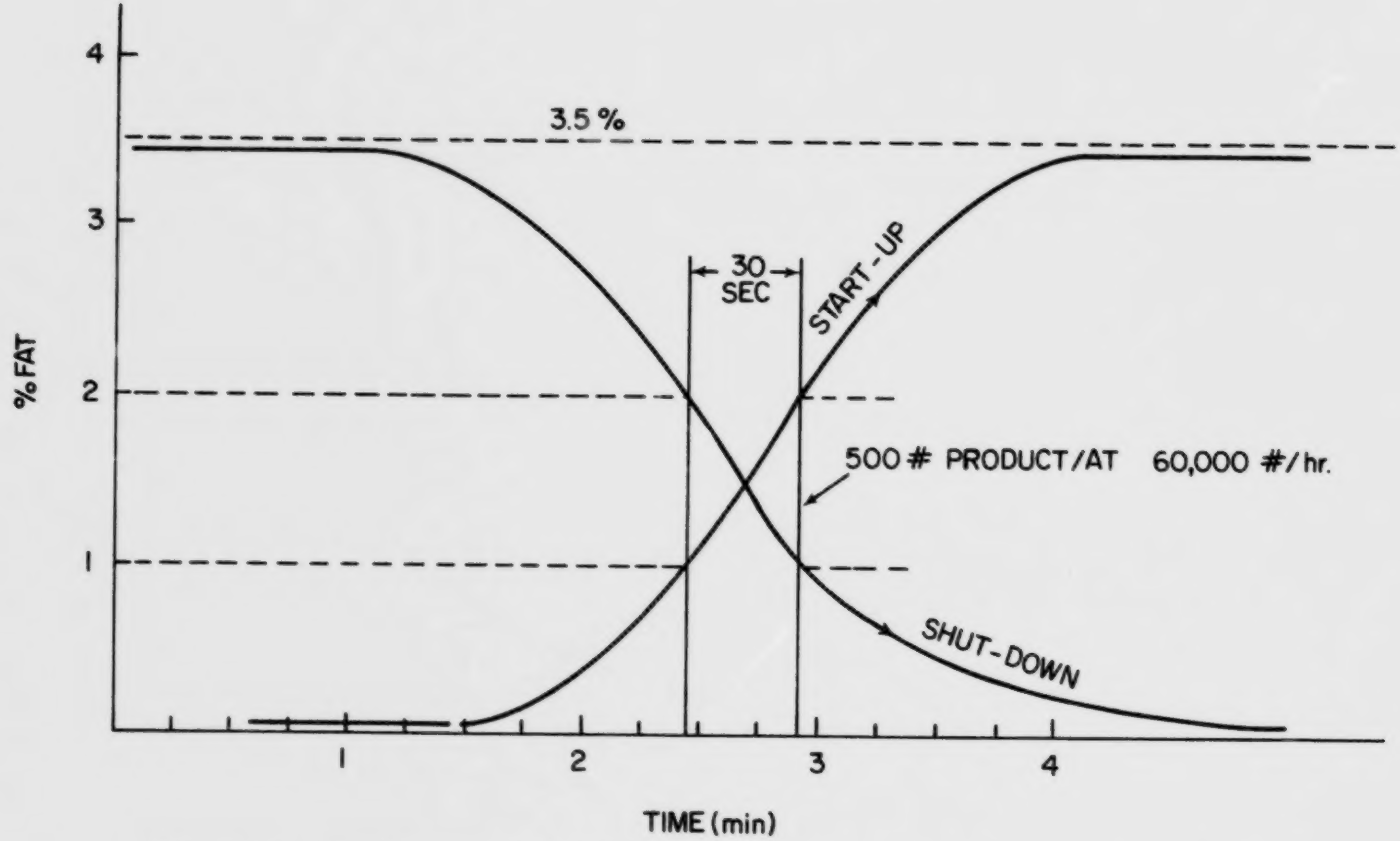


Figure 33 - Fat losses as a function of time during start-up and shut-down of a 60,000 pound/hour HTST pasteurizer

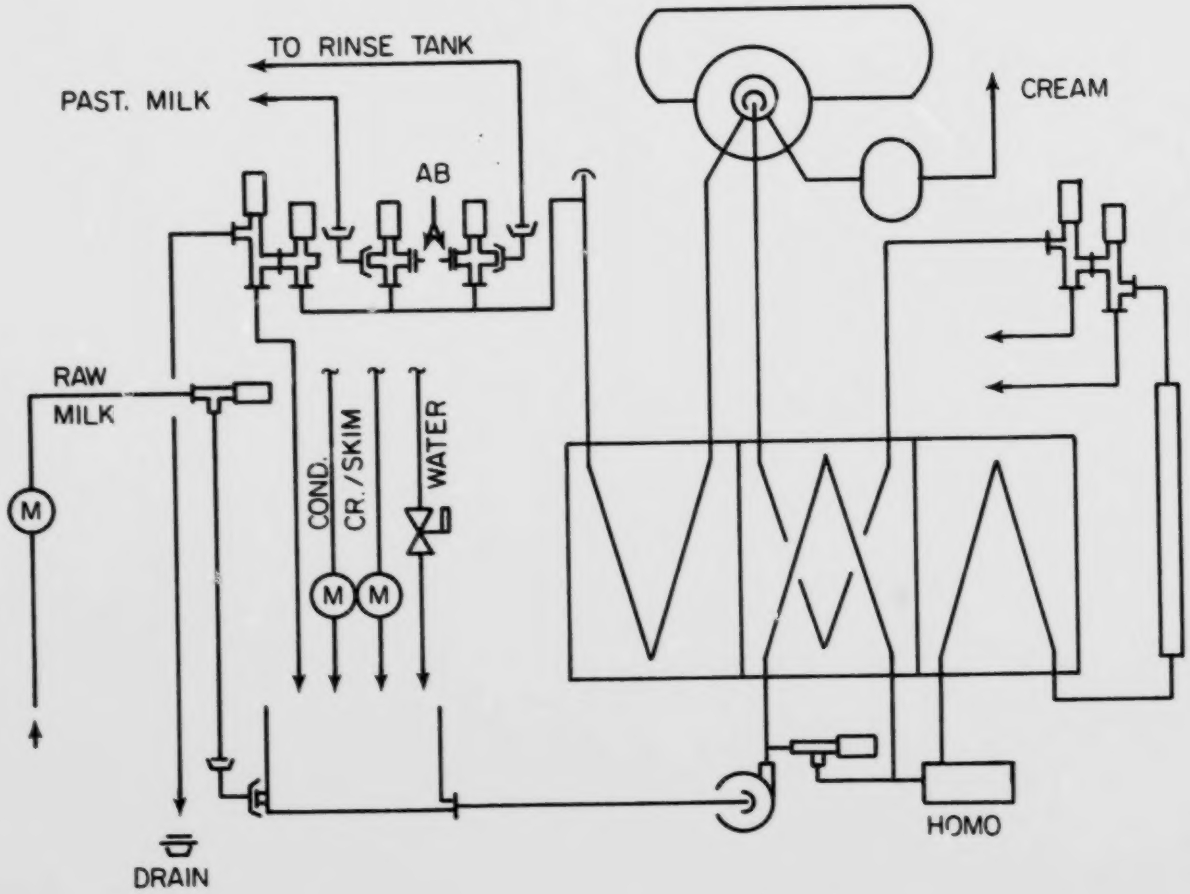

TO RINSE TANK
PAST. MILK
AB
CREAM
RAW
MILK
M
COND.
CR./SKIM
WATER
M
M
HOMO
DRAIN

Figure 34 - Diagrammatic presentation of automated system for minimizing milk losses by continuous blending of products at HTST pasteurizer balance tank, eliminating need for pasteurizer shut-down during product change-overs

milk, and reverting back homogenized milk for changing to the next surge tank, it is possible to make one product changeover after another in the pasteurization system with homogenized as the intermediate, rather than water; thus avoiding the loss of product resulting from start-up and shut-down on water. At the same time, it will eliminate the utilization of the intermediate tanks and thus saves the product normally adhering to the walls of these tanks which would go to the sewer as waste at the rate of about 0.2 pound per thousand pounds of product processed for low viscosity products and up to three pounds per thousand pounds for cream.

SEGREGATION OF WASTES

When planning new plants, or remodeling plants that exist, consideration should be given to the segregation of those sewers receiving high waste in BOD content from general floor and area drains. One example of new design possibilities would be to combine up-drains at HTST constant level tanks as CIP units and CIP type centrifugal machines into a single separate sewer system. This system may be initially connected to the existing system outlet of the plant but later, if desired, it could be connected to a retention tank to permit metered discharge of the high waste load over a prolonged period of time; it might, in fact, be subjected to some type of pre-treatment. Illustration of such a segregated drain system is shown in Figure 35.

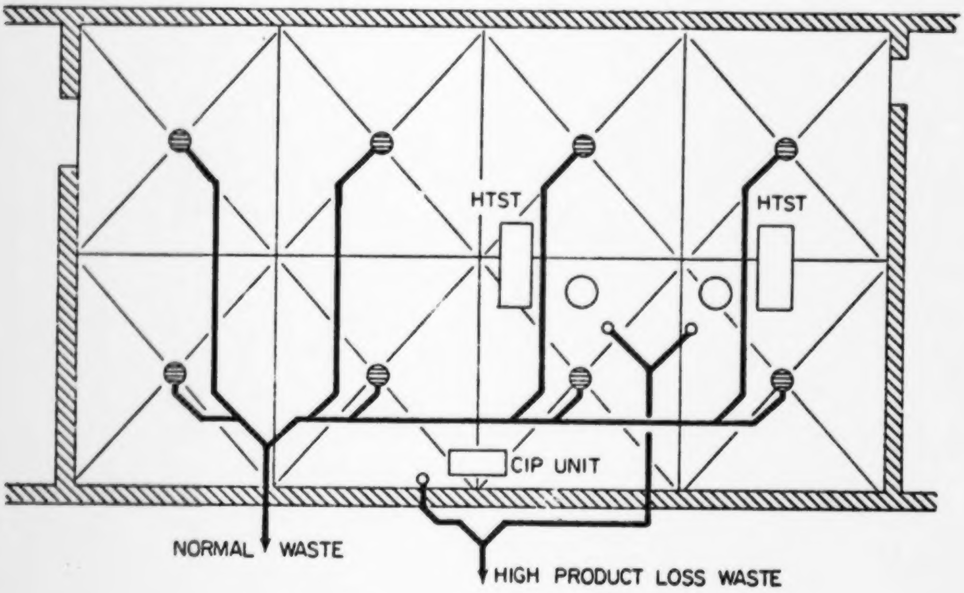


Figure 35 - Floor drain system for segregation of high and low solids waste waters in a dairy food plant

Similarly, lubricants, milk in filling areas, and solid particles in cottage cheese filling operations might be segregated by a separate drain system and collected at a central point for pre-treatment. The installation of desludging centrifuges on whey operations, especially cottage cheese whey operations, can materially reduce the BOD level of whey through the removal of fat and curd fines. In pilot trials at The Ohio State University, the BOD of cottage cheese whey has been reduced from 45,000 to 30,000 by the use of a desludging clarifier and the utilization of the recovered curd as a product for baking purposes.

Detergents Concentration and Volume

Utilization of automated cleaning systems provide control of concentrations of detergents and sanitizers and generally result in a reduction in the amount of detergent used/pound of milk processed. Recently, a new design for a CIP system was introduced in Denmark (Fig. 36) to reduce the amount of detergent wasted (167).

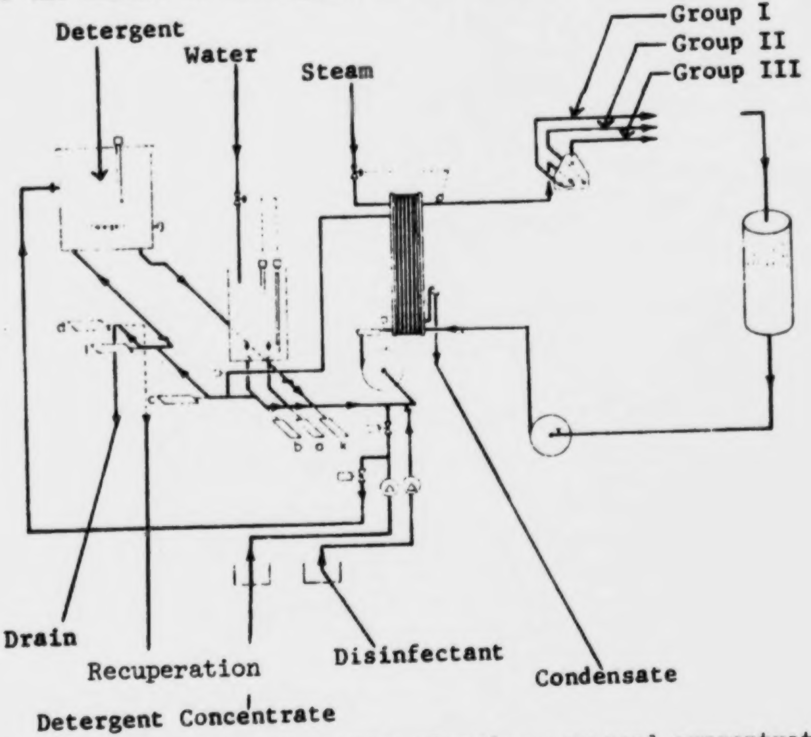


Figure 36 - CIP system to reduce cleaning compound concentration in dairy food plant waste water. (On start-up of tank cleaning the rinse water is pumped from the balance tank through the T-valve "a" to the tank detergent distributor. From the tank the detergent is returned to the cleaning unit. At this point the first batch of rinse water with product remnants is led via the flow diversion valve "d" to the collecting tank. At the end of the pre-rinse period the T-valve "a" is closed and the T-valve "k" activated, whereby detergent is pumped into the cleaning circuit. As soon as the system has been filled, the flow diversion valve "c" is activated and the T-valve "k" closes.)

Control of Waste Water Through By-Product and Waste Product Utilization

Because of the national attention and visibility of whey as a waste product, the dairy industry is well aware of the significance of using whey as a food or feed product to minimize pollution and to gain a profit from such operations. They are less aware of the potential in respect to the utilization of product rinses, dilute milk solutions resulting from start-up change over and shut-down of pasteurizers on water, which is a major source of BOD in most food milk plants and the recycling or utilization of returned product.

Whey: The complete removal of whey from waste waters is a continuing problem in the United States, in part, because of the large volume of material to be handled (about 20% of all the milk processed ends up as whey of one type or another), the limited market for whey solids, and technological problems in developing products from whey.

No attempt will be made to outline in detail all of the potential methods by which whey can be utilized (152, 418, 425, 517, 699, 766, 871, 1045, 1068, 1218, 1235, 1245). Certainly there is no single solution to the problem; it will require a full gamut of different types of products and processes in order to divert whey from waste waters. Some of these products and processes already exist, whereas others await development. Acid whey, because of the presence from 0.5 to 0.7% lactic acid, provides problems in respect to drying the material and also in respect to its utilization in food.

Foam spray-drying (92, 201, 425), foam mat drying (482), reverse osmosis (478, 672, 673), gel filtration (766), electrodialysis (1280), hydrocolloid protein precipitation (434), ultrafiltration for protein recovery (478, 673), utilization or the growth of yeast protein (18, 58, 345), fermentation (129, 192, 908, 1076) and animal feed use (213) are all methods which have potential for the conversion of whey into more usable forms.

A major problem in respect to the elimination of whey from waste waters lies in the marketing of the product so far as a profitable return on the product is concerned. However, all the methods have applicability for converting whey into usable products for feed, if not for food, and can result in a reduction of cost to a dairy operation where they are faced with an absolute limit on BOD in the waste water or where they are paying a surcharge on BOD at the present time. In this connection it might be well to note that one plant recently built to produce food grade whey powder has been diverted to feed grade, a lower profit product, because of the lack of a market for the dried whey which could be attributed, in part, to low-cost imported dry milk solids utilized in preference to whey.

One of the most promising developments in respect to whey utilization lies in the recoverability of the protein fraction, separate from the rest of the whey, which has unique nutritional and functional properties. The nutritional value of the whey protein exceeds that of casein; the protein has unique whipping and emulsifying properties. Removal of the protein from the whey reduces the whey solids approximately 13% and the BOD approximately 20%.

Methods for economically removing lactic acid or sodium lactate from acid whey, and practical procedures for converting lactose into its simple components, galactose and glucose, are needed to provide for further market potential of whey solids. At the present time, the problem of whey utilization would appear to be more oriented to economical and marketing considerations than to needs for new technology.

The available technology would appear to adequately provide for complete utilization of sweet whey as food or feed material. The market and economic possibilities need to be improved.

Buttermilk solids: With the increasing utilization of continuous churn processes and with the decline in butter plants, the disposition of buttermilk is becoming a minor problem. Most of the buttermilk in the country at the present time is being withheld from waste water and is either dried for food or feed use through being sold directly for feed.

Recoverable milk solids: As previously indicated, the potential exists for elimination of all the milk solids present in rinse waters from tank truck storage tanks, lines and equipment, saving the milk solids diverted to drain in the start-up, changeover, and shut-down of HTST pasteurizers and removal of milk solids put into the waste water by virtue of returned products. It would appear that up to one pound of BOD per thousand pounds of milk processed could be eliminated through the collection and utilization of these solids. In the case of highly viscous products, such as cream, churned buttermilk, sour cream, yogurt, ice cream mix and similar products, the amount of BOD that could be recovered from waste waters might be as high as three pounds per thousand product in some plant operations. At the present time, these diluted milk solids are considered to be adulterated products by many health officials and changes in laws and regulations will have to permit their utilization in foods. There is need for further investigation to optimize methods for segregation and utilization of these dilute materials. The possibility exists at the present time of using them in ice cream mix or any other product where solids can be added to the material. The possibility also exists of utilizing reverse osmosis to concentrate the materials (673). However, this will require additional membrane technology since protein and lipids tend to foul the reverse osmosis membranes currently in use.

SECTION VIII

DAIRY FOOD PLANT WASTE WATER TREATMENT

Dairy food plant waste waters are treated by common biological methods, with the waste waters from about 90 percent of the approximate 6500 dairy plants in this country being treated currently by municipal treatment facilities. Dairy food plant effluents differ considerably in composition from municipal sewage; they have a much higher BOD_5 level, a higher ratio of carbon to available nitrogen, and a comparatively low suspended solid content. Owing to the nature of dairy food plant operations, the effluent generally shows short-period fluctuations in strength and volume during the day, considerable day-to-day variation and some long-period variations of a seasonal nature. Based on information available, wastes take on the characteristics of dairy food plant wastes when the BOD_5 contributed by the milk solids equals or exceeds about 50 percent of the total BOD or the BOD_5 contributed by whey exceeds 10 percent of the total BOD.

A function of biological treatment processes is to remove organic matter from the effluent through the metabolic means of oxidation and cell synthesis. Biological processes are categorized according to the method of contacting the organic food with the microflora and the presence or absence of molecular oxygen. Aerobic processes are universally used today for treatment of dairy food plant waste waters. The prevalent systems utilized by dairy food plants and municipalities treating dairy food plant waste water include: activated sludge, trickling filters, oxidation ponds, spray irrigation, ridge and furrow irrigation and combinations of these methods. The treatment method employed by any given dairy plant will depend on a variety of factors, including the volume and strength of effluent waste water, the size, location and type of plant, management factors, availability of municipal sewage facilities, existing state and local legislation and economics.

Since all biological treatment methods involve the growth and metabolism of a variety of microorganisms, attention will be directed first to a discussion of the microbiology of dairy food plant waste water treatment, followed by a discussion of present knowledge and practice of the various biological treatment processes as applied to dairy food plant waste water.

MICROBIOLOGY OF DAIRY FOOD PLANT WASTE WATER TREATMENT

Mechanism of Biological Oxidation

All biological treatment systems can be considered in respect to the same fundamental principles, irrespective of the waste being treated (670a). The success of any given biological treatment system is dependent upon the ability of the microflora to utilize the food supply in the waste

Preceding page blank

and the relative rate of removal of the microorganisms in relation to their reproduction. The high and unequal organic loads in dairy food plant waste waters does place a considerable stress on the biological processes that take place.

The growth of microorganisms, as a function of time, after the introduction of organic material in the waste water can be estimated according to the equation (670a):

$$dX/dt - Y(dF/dt) - bX \qquad [1]$$

where dX/dt = the net growth rate of microorganisms in mass per unit of time;

dF/dt = rate of waste utilization per unit of time;

X = mass of microorganisms present;

Y = growth yield coefficient in mass of microorganism produced per unit mass of waste consumed; and,

b = organism decay rate, time^{-1}.

Thus, the rate of growth of microorganisms is proportional to the rate of waste utilization minus the loss in microbial mass due to the death and decay of the microorganisms. The mass of microorganisms in the volatile suspended solids varies as a function of the amount of nonmicrobial organic matter complexed to the microbial cells. The rate at which the organic matter is consumed by the microflora is a function of the rate limiting nutrient(s), which may change as a function of time. The initial rate-limiting nutrient in dairy food plant wastes is considered to be lactose (5) and the rate-limiting enzyme in the utilization of lactose is β-glactosidase (1007). In addition, low nitrogen or phosphorous concentrations can be rate limiting. In dairy food plant wastes the phosphorous content is generally nonlimiting, whereas nitrogen is frequently considered to be a major limiting factor. Although the BOD/N ratio of milk solids is approximately the same as that considered to be optimum (20:1), the availability of the nitrogen is much less because it is associated primarily with proteins that are not degraded until after all of the lactose is degraded (3).

The rate of waste utilization is frequently presented in the form of an analogy to the Michaelis-Menten equation for enzyme rate kinetics, applied in the form:

$$\frac{dF/dt}{X} = \frac{K\ S}{K_s + S} \qquad [2]$$

where S is the concentration of substrate surrounding the microorganism;

K_s = waste concentration at which the rate of waste utilization is half the maximum rate; and

K = maximum rate of waste utilization at a high waste concentration.

The substrate removal velocity (dF/dt)/X is also called food-to-microorganism ratio.

McCarthy (670a) combined the two previous equations to give:

$$\frac{dX/dt}{X} = \frac{YK\ S}{K_s + S} - b \qquad [3]$$

where dX/dt/X is the specific net growth rate, and the maximum growth rate equals (YK-b).

In continuous operation, a given quantity of microorganisms is deliberately wasted to promote a steady-state equilibrium between waste stabilization and microbial growth. In a well-mixed system, the rate of waste treatment (dF/dt) is equal to $(S_o-S)Q$, where Q is flow rate, S_o and S are the treatment feed and effluent concentrations, and the efficiency of waste treatment is $100(S_o-S)/S_o$.

The reciprocal of specific growth rate gives the sludge age or solid retention time, θ_c, i.e.,

$$\theta_c = X/(dX/dt) \qquad [4]$$

or

= suspended solids in system/suspended solids removed from system each day.

When the sludge decay is small and S is much larger than K_s, the minimum solids retention time at which the biomass leaves with the effluent is faster than it can grow becomes:

$$\theta_c^m = 1/YK \qquad [5]$$

The excess biomass which must be removed for separate disposal may be expressed in terms of θ_c, for

$$\frac{dX}{dt} = Y(dF/dt) - bX \qquad [1]$$

becomes

$$\frac{dX}{dt} = Y(dF/dt) - b\theta_c(dX/dt) \qquad [6]$$

McCarthy has shown the nitrogen and phosphorous requirements of microbial treatment process in which the cells are about 12% nitrogen and 2% phosphorous to be:

$$N = 0.012\ (dX/dt) \qquad [7]$$

$$P = 0.02\ (dX/dt) \qquad [8]$$

where

N = pounds of nitrogen per day, and

P = pounds of phosphorus per day.

For aerobic systems, which are used in almost all dairy food plant waste treatment systems, oxygen is required for the system, and the amount required is:

$$C = dF/dt - N(dX/dt) \qquad [9]$$

or

$$C = (1-nY)(dF/dt) + nbX \qquad [10]$$

where C is the pounds of oxygen used per day, and n is the conversion factor equal to the oxygen required to oxidize a unit mass of cells to inorganic end products and approaches 1.4 when Y is expressed in pound of volatile suspended solids per pound of waste water COD.

The biological growth yield, Y, which indicates both the quantity of solids which will require disposal as well as nitrogen phosphorous required for treatment, ranges from 0.3 to 0.4 for COD and from 0.4 to 0.6 for BOD_5 consumption. Adamse (3) reported values of 0.45 for BOD_5 values of less than 1000 ppm and 0.34 for BOD values of greater than 2000 ppm. The full meaning of these findings will require further work.

The rapid incorporation of milk constituents (lactose, protein) into the cell biomass after the introduction of skim milk into an activated sludge system has been interpreted to indicate a very rapid assimilate of the organic matter of dairy food plant wastes (468). However, Adamse (5) reported that the protein in milk wastes was not utilized until after all of the lactose was degraded. Thus, the initial incorporation of protein, and possibly, lipid, into the biomass may be through complex formation and does not represent an increase in cell yield (Y) in terms of cell numbers. This view is supported in part by industrial observations and practices, where long retention times are required for the treatment of dairy food plant waste.

The fact that dilute whey, and especially acid whey, has created problems in biological waste treatment systems may be explained on several bases: (a) the lactate ion may exhibit a feedback inhibition or repression of β-galactosidease activity, (b) the whey proteins may complex to the cell wall and interfere with permease activity, (c) the whey proteins may be more difficult to degrade than casein and provide a low available nitrogen level, or (d) a combination of one or more of these. The lactate ion has been shown to exert a feed back repression for the production of β-galactosidease in certain microorganisms, and might be expected in the biological treatment systems for dairy food plant wastes. Dilute cottage cheese wash water (2000 ppm BOD) can cause extensive foaming of an activated sludge biological treatment system. An unpublished investigation of this foam in the Department several years ago indicated that the foam was a complex of the major whey protein, β-lactoglobulin, and microbial cells in which bacilli predominated. Other work in this Department has shown that Bacillus cereus cannot degrade β-lactoglobulin as readily as other milk proteins, and thus, the nitrogen may be much less available when whey proteins are the only source of nitrogen.

The specific metabolic pathways operative in the biological degradation of milk constituents in waste treatment have not been elucidated, but can be presumed to be essentially the same as for other systems (1007).

MICROFLORA

Activated Sludge

Activated sludge is composed of bacteria, fungi, protozoa, rotifers, and sometimes nemotodes (685). Bacteria, the most important group of microorganisms, are responsible for the stabilization of the organic matter in floc formation. All types of bacteria make up the floc of the activated sludge system. Previously it was thought the activated sludge was formed by the bacteriam Zoogloea ramigera, but it has been shown that all bacteria contribute to the floc and that the Zoogloea play a minor role. The chemical composition of the waste being treated determines the bacterial genera which will predominate in the system. Proteinaceous wastes favors Alcaligenes, Flavobacterium and Bacillus, whereas carbohydrate or hydrocarbon wastes favors the dominance of Pseudomonas species. Yeasts and molds are not considered to be desirable, but develop under conditions in which the waste has a high carbohydrate content, unusual organic compounds, low pH or nutritional deficiencies. With certain industrial wastes nonfilamentous fungi can produce an activated sludge with normal settling characteristics, but generally fungi interfere with proper settling of the sludge.

Protozoa do not contribute directly to the stabilization of organic materials in the flocs but live off the floc forming bacteria. Ciliata is reported to be the primary protozoa in domestic waste activated sludge. With a high "free swimming" bacterial population, free swimming ciliated protozoa will dominate; as the bacteria population is reduced, stalked forms of ciliate protozoa dominate. Rotifers are not often seen in activated sludge systems because of limited food supplies. However, in complete oxidation type of activated sludge systems, rotifers are the predominant animal forms.

The microflora of municipal activated sludge has been characterized by several investigators including Dias and Bhatt (291). The dominant bacteria in order of decreasing frequency were: *Zoogloea*, *Commanmonas*, *Pseudomonas*, *Micrococcus*, *Flavobacterium*, *Acromobacter*, *Alcaligenes*, *Corynebacterium*, *Bacillus*, *Brevibacterium*, *Spirillum* and *yeasts*. All these organisms and others have been found in activated sludge from dairy waste treatment. However, the dominant microflora reported by various investigators for the dairy activated sludge are quite different from that of domestic activated sludge. *Zoogloea ramigera*, which was once considered to be the predominant purifying microorganism in domestic activated sludge, has been only rarely reported in dairy activated sludge (685).

A considerable amount of research on aerobic waste treatment has been conducted by Porges and his collaborators (833). They isolated and studied the bacteria present during the rapid biochemical oxidation of skim milk ("dairy") wastes. These authors found that the microflora differed in the assimilative and endogenous phase of the oxidation process. The bacteria isolated from their system, which utilized skim milk as a substrate is shown in Table 59, in comparison to results from one of Adamse (3) reports of actual dairy plant wastes. The differences in microflora may relate to the differences in waste composition. The most extensive investigations of the microbiology of the activated sludge from dairy waste treatment has been conducted by Adamse (3, 4, 5, 6). Adamse, who studied the microflora in an oxidation ditch of a commercial dairy plant and in a laboratory system utilizing a dried dairy waste as a substrate, was able to duplicate the microbiology of the two systems. Adamse, and other investigators, (4) have reported that approximately 50 to 60 days is required to stabilize the microflora in a dairy waste. His system stabilized at a sludge volume index of 30.2 ml per gram, a relative stability of greater than 90% and a BOD reduction of 90.9%. In their particular experiments COD reduction was usually greater than BOD, achieving approximately 98%. He reinvestigated the bacterial composition in the endogenous and assimilated phases reported by Jasewicz and Porges (514), and found no differences in the groups of organisms present in the two phases of biological oxidation (Table 60).

Adamse concluded that the adaption of the bacterial flora to the supplied waste was a slow process and that the composition altered the natural milk microflora in time until it consisted predominantly of *Coryneform* (arthrobacter-like bacteria). Next in significance in his studies were the yeasts and *Achromobacter*.

Gillar and Marvan (398) also studied the microflora of dairy activated sludges and identified two common types of biocenosis in the sludge. They separated these into "yeast types" of organisms and flagellate types of organisms. The yeasts, which were most frequently

Table 59 - Predominant Bacteria in Skim Milk Sludges

Genera	In Percent of Total Numbers Isolated		
	Assimilative Phase*	Endogenous Phase*	Complete**
Achromobacter	-	2	17.0
Alcaligenes	-	26	5.4
Bacillus	31	8	1.5
Bacterium (B. linens)	43 (40)	-	-
Brevibacterium	-	-	1.0
Caulobacter	-	-	0.9
Corynebacterium	6	-	-
Enterobacteriacea	-	-	2.0
Flavobacterium	8	34	-
Mycobacterium	6	-	0.2
Micrococcus	2	14	1.3
Pseudomonas	4	16	-
Yeasts	-	-	3.9
Molds	-	-	0.9

*Jasewicz and Porges (514); Porges (1960).
**Adamse (3)

Table 60 - Microbial Composition, in Percent of the Total Number of Strains Tested, of the Activated Sludge in the Endogenous and in the Assimilative Phase (a and b are duplicate flasks; samples were taken 28 (1) and 56 (2) days after the start of the experiment) (3)

Organisms Isolated	1 Day				2 Days			
	a		b		a		b	
	End.	Ass.	End.	Ass.	End.	Ass.	End.	Ass.
Pseudomonadacea	18.7	26.0	4.0	10.0	6.1	4.1	4.0	-
Achromobacteraceae	50.0	54.0	36.0	12.0	20.5	10.0	10.0	-
Enterobacteriaceae	-	4.0	2.0	2.0	-	-	-	-
Corynebacteriaceae	22.9	12.0	58.0	70.0	59.3	83.8	74.0	79.5
Brevibacterium	2.1	2.0	-	-	2.0	-	-	2.1
Mycobacteriaceae	-	-	-	2.0	-	-	-	2.0
Bacillus	-	-	-	-	-	-	-	2.1
Micrococcaceae	2.1	-	-	-	2.0	2.1	-	-
Sarcina	-	-	-	-	-	-	-	2.0
Caulobacter	-	-	-	-	2.0	-	4.0	2.1
Yeasts	-	2.0	-	2.0	6.1	-	8.0	8.2
Mould	4.2	-	-	2.0	2.0	-	-	2.0

of the Saccharomyces genera dominated in the waste treatment system at low pH values (low 5.5). Yeasts were found only when the BOD_5 of raw wastes were greater than 1000 ppm. The purification efficiency of the yeasts ranged from 30 to 60%. The flagellate organisms generally dominated with pH values above 5.5 and BOD_5 values below 1000. The flagellates of the Boda genus were generally accompanied by Spirillum, Sarcina and Beggiatoa. In some cases they found neither yeast nor flagellates present, with the biological oxidation being performed entirely by nonfilamentous bacteria of unidentified genera. These investigators found a progression of microorganisms in the various stages of the three-stage activated sludge process they studied. In the first stage, Streptococcus organisms prevailed, in the second stage the major genes of microorganisms was still Streptococcus with yeasts emerging. A few colorless flagellates, filamentous bacteria and mycelia fragments of Deuteromycetes were found, with some rotifers being present.

Lembke (621) investigated a 24-compartment sludge system for dairy wastes. Lactic acid bacteria predominated in the first and second compartments, became less in number and were not found beyond the twelfth compartment. Coliform organism became the dominant component of the microflora in the later compartments, with large numbers of molds; the last compartment contained microorganisms, including Pseudomonas, growing well at low temperature. The acidity became quite high after the initial fermentation by the lactic acid organisms and disappeared in later compartments. Most of the organisms were capable of fermenting lactate. It was indicated that organisms able to degrade lipids were consistently present and the results indicated that fat was decomposed in the early stages of the process, but protein degraded slowly.

Chian and Matellas (226) studied the population characteristics of continuous mixed cultures on glucose-butyrate and glucose-lactose media seeded with polluted river water. The glucose was preferentially utilized in both cases with production in large amounts of acetate. Pseudomonas, Achromobacter and Coliform organisms predominated in low substrate concentrations.

Pipes (815a) investigated the microflora of various activated sludge plants, six of which either were totally or partially treating dairy plant wastes. Each plant was investigated at different seasons of the year. Table 61 summarizes the results for all of the plants with dairy plant wastes. Information is provided in respect to the numbers of particulate filamentous organisms, types of protozoa, dominant bacteria, other identified microorganisms, sludge volume index, loading, BOD reduction, characteristics of the floc, and special problems encountered. They found a large number of filamentous bacteria which belonged to the genus Bacillus, Arthrobacter, Sphaerotilus, Beggiatoa and Nocardia. Neither Pseudomonas, Achromobacter or Flavobacter were noted in their studies. They reported that it was impossible to determine which type of microorganism was involved in sludge settling problems, which included bulking, deflocculated sludge and pinpoint sludge.

Table 61 - Activated Sludge Microbiology and Waste Plant Characteristics

Plant	Type of Waste	No/g x 10^{-3}		SVI	Loading BOD/Pounds MLSS	BOD Reduction Percent	Dominant Bacteria	Other Bacteria Present	Protozoa and Invert.	Sludge Classification	Problems
		Particles	Filaments								
Milton, Wis.	Domestic & Milk Recv. Plant Wastes	53	93	82	0.78	74	Beggiatoa	Bacillus Actinomycetales	Stalked Ciliates & Flagellates	Defloc.	Loss of solids from clarifer
		57	110	148	0.30	64	None	Bacillus Actinomycetales Beggiatoa	Stalked Ciliates & Flagellates	Defloc.	Loss of solids from clarifer
		164	1115	250	0.80	91	Bacillus Arthobacter Brevibacterium	Actinomycetales Spaerotilus Beggiatoa	Stalked Ciliates & Flagellates	Defloc.	Loss of solids from clarifer
		315	4770	964	0.52	90	Beggiatoa Arthobacter	Bacillus Actinomycetales	Stalked Ciliates & Flagellates	Bulking	Low solids in aeration tank
Woodstock	Domestic & Dairy (30% of BOD)	2060	190	38	0.64	87	None	Bacillus Actinomycetales	Stalked Ciliates Flagellates Rotifers	Pinpoint Floc	No dairy waste this sample
		509	110	50	0.02	59	Bacillus Actinomycetales Sphaerotilus	None	Stalked Ciliates Flagellates Rotifers	Pinpoint Floc	Loss of solids
		1930	590	65	0.018	69	Bacillus Actinomycetales Sphaerotilus	None	Stalked Ciliates Flagellates Rotifers	Pinpoint Floc	Loss of solids
		1270	140	67	0.019	79	Bacillus Actinomycetales Sphaerotilus Arthobacter	None	Stalked Ciliates Rotifers	Pinpoint Floc	Loss of solids
Spiney Run, Illinois	Milk Wastes	497	610	163	0.77	56	Bacillus	Actinomycetales Sphaerotilus	Flagellates	Defloc.	Continuous loss of sludge in secondary clarifier
		225	560	59	0.29	97	None	Bacillus Actinomycetales	Flagellates & Ciliates	Normal	Continuous loss of sludge in secondary clarifier
		150	2630	263	0.43	17	Sphaerotilus Arthrobacter Brevibacterium	Bacillus Actinomycetales	Flagellates & Ciliates	Defloc.	Low solids in aeration, high solids effluent (241 ppm BOD effluent)

Table 61 - Continued

Plant	Type of Waste	No/g x 10^{-3}		SVI	Loading BOD/Pounds MLSS	BOD Reduction Percent	Dominant Bacteria	Other Bacteria Present	Protozoa and Invert.	Sludge Classification	Problems
		Particles	Filaments								
		85	260	36	1.10	45	Sphaerotilus Beggiatos Brevibacterium	Bacillus Actinomycetales	Flagellates & Ciliates	Defloc.	Low solids in aeration, high solids effluent (369 ppm BOD in effluent)
Woodstock	Milk Wastes & Cottage Cheese Whey	886	1270	115	0.053	87	Actinomycetales	Bacillus Sphaerotilus	Flagellates & Ciliates	Defloc.	Foaming & loss of solids in effluent
		1640	4910	199	0.13	98	Bacillus Actinomycetales	None	Flagellates	Defloc.	Foaming & loss of solids in effluent
		508	265	150	0.13	99	Bacillus Actinomycetales	None	Flagellates & Rotifers	Defloc.	Foam, high solids in mixed effluent
		659	310	122	0.086	98	Bacillus Actinomycetales	None	Amoeba & Ciliates	Bulking	Foam, loss of solids in effluent
Antioch, Illinois	Domestic & Dairy & Ink	451	800	79	0.29	52	Bacillus	Actinomycetales	Stalked Ciliates Flagellates Amoebas Rotifers	Pinpoint Floc	None
		328	240	54	0.21	97	Bacillus Begiatoa	Actinomycetales	Stalked Ciliates Flagellates Amoebas Rotifers	Pinpoint Floc	None
		204	140	46	0.31	97	None	Bacillus Actinomycetales	Stalked Ciliates Flagellates Amoebas Rotifers	Normal	None
		631	2060	296	0.29	96	Actinomycetales Beggiatoa	Bacillus	Ciliates Flagellates Amoebas Rotifers	Bulking	Poor return sludge capacity
North Shore	Domestic & Dairy (Cheese)	177	170	44	0.85	97	Bacillus	Actinomycetales	Rare Stalked Ciliates	Pinpoint Floc	Billowing & septic sludge
		430	190	36	0.55	98	Sphaerotilus	Bacillus Actinomycetales	Stalked Ciliates Flagellates Amoebas	Pinpoint Floc	Billowing & septic sludge
		166	70	41	0.22	95	Sphaerotilus	Bacillus	Cilliates Flagellates	Normal	Billowing & septic sludge
		214	90	42	0.18	47	Bacillus Actinomycetales	Sphaerotilus	Cilliates Flagellates	Pinpoint Floc	Billowing & septic sludge

Protozoa, predominantly stalk ciliata type, were present in most of the sludge samples and no correlation was observed between the protozoa and plant performance or settling problems. Rotifers were present in large numbers in about 50% of the sludge samples and were conspicuously absent in the flocculated sludges, but present in equal proportions in normal sludge samples, bulking sludge samples, and samples showing pinpoint floc. The presence of rotifers was associated with low loading (less than 0.16 pound BOD/pound MLSS) and better performance.

Trickling Filter

The microorganisms in the trickling filter reflect the facultative nature of the system in which the predominating microorganisms are aerobic and facultative anaerobic organisms. Obligate aerobic sporeformers bacillus are reported to be in the upper aerobic surfaces with the obligate anerobes Deslivibrio present at the stone interface. Psychrotropic organisms include varied species of Pseudomonas, Alcaligenes; Flavobacterium and Micrococcus were present in between (11). Fungi are also present but the competition for foods generally limits the growth of these fungi under normal environmental conditions. Algae grow on the upper surfaces of the filter but do not contribute to the overall stabilization of the waste. Protozoa are the predominate animal forms found in trickling filters with free swimming ciliates predominating the filter surface, with the stalked ciliates predominating in the lower regions. Protozoa predomination will vary from filter to filter and within a single filter in response to changing food supply (11).

The filter will continue to remove organic matter so long as the microorganisms are reduced to the organic concentration of the bound water layer between applications of waste. The top layer of microorganisms are stimulated to active metabolism by high organic concentrations as fresh wastes flow past. A portion of the organic matter is converted into new cells while an equivalent portion is oxidized to furnish the energy for synthesis. The rate of microbial activity is directly proportional to the organic concentration. The end products of anaerobic metabolism are organic acids, aldehydes, and alcohols, which diffuse slowly out of the cells toward the surface layer of microorganisms where along the upper layer the microorganisms are receiving organic matter towards the top and the bottom. Cell growth continues until the food supply is diminished, metabolism stops, and a point is reached where the cells die and lyse. The lysed products diffuse to the surface the same as the anaerobic end products. Lysed cells also destroy the surface responsible for holding the microbial mass to the stone or plastic support. Microbial flocs drop from the stone and the filter cycle starts over. As the microbial cells build up, efficiency increases; with continued build-up the efficiency begins to fall slightly and there is a rapid loss of efficiency as the growth drops off. Where shock loading occurs, as with dairy wastes, there is a tendency for loss of the biomass from the support and a resulting wide fluctuation in the efficiency of the treatment system.

The organisms isolated in the trickling filters by Wattie (1230) were floc forming organisms which were closely related to the organisms isolated in the activated sludge.

Edmondson and Brasis (318) isolated *Pseudomonas cyanogens*, *Pseudomonas putrifaciens* and Pseudomonas viscosa as the dominant microflora from a trickling filter system treating dairy plant wastes. Giller (396) found primarily *Zoogloea* bacteria; occasionally *Beggiatoa* and stalk-forming ciliates. The best purification was found in the presence of the protozoa, presumably because of their control of the thickness of the biomass on the filter support. Halasz (424) found that three distinct groups or organisms were distinguishable on trickling filters: one which is effective in reducing BOD immediately, one which became active about two days after loading, and a third, effective only after three to four days. During the treatment the floc disintegrated and dead cells were released to the effluent. The microflora was not specifically identified.

Calvert (201, 202) in investigating trickling filter treatment of dairy wastes found that whey wastes were much more difficult to handle than municipal wastes, creating a deterioration of the biomass with a shift in dominant microflora and a change in the types of dominant *Aerobacter* species present. Whey induced heavy yeast growths at the surface of the rock and subsequent ponding of the filter.

In a study of uneven distribution of dairy waste water over a trickling filter, Januszko (513) found that fungi developed in the underloaded sections with only slight vertical stratification and inefficient purification.

In investigating the activity of a rotating biological contacter on dairy wastes, Antonie and Welch (121, 122) found that filamentous organisms were most dominant including, *Geotricum candidum*, *Bacillus cereus*, *Zoogloea filipendula*, *Pseudomonas denitrificans*, *Aerobacter arogenes* and *Eshirichia coli*. The biological activity in this type of treatment can be considered to be essentially identical in principle to the trickling filter.

Lawton (612) found that loading a trickling filter with whey at excess of 1500 parts per million resulted in abnormal microbial growth and reduced BOD reduction in the presence or absence of sodium chloride associated with cheese whey.

Svoboda, (1083, 1086) studying trickling filters, found that lactic acid producing organisms do not degrade large amounts of lactose in dairy wastes, whereas *Oospara lactis* degraded lactic acid.

Oxidation Ponds

The stabilization pond is an aerobic treatment method depending upon microorganisms and certain flagellated protozoa. The system is generally in balance with algae, with the algae utilizing the CO_2 ammonia and phosphate released from the microorganisms (11). The microorganisms in oxidation ponds are the same as those existing in other treatment processes. Bacteria and algae, together with algae, dominated the microflora and protozoa, while rotifers were present under certain loading conditions. The predominate organisms in domestic waste treatment systems are Pseudomonas, Flavobacteria and Alcaligenes.

Rascke (864) found 28 species of 20 genera of algae in a milk waste stabilization pond; Euglena acus was the most prevalent. Chlorella and Scenedesmus were not found in large numbers. Sharkawi and Moawad (998), in studying oxidation ponds treating dairy wastes, found that the initial organisms were unicellular algae such as Chlorella schinadesmus and Clamydomonas. These algael types did not develop in the presence of whey; the subdominant microorganisms consisted primarily of Selenastrum, together with diatomes and protozoa. The introduction of 100 ppm whey caused development of acidity and shortly after this the pond became septic. After reducing the whey wastes, a new algal flora developed made up of Pandorena, Nevicula, and Oocystis, which appeared to be much better adapted to milk wastes. The system was a two-pond system and the organisms found in the second pond were generally similar to those found in the first pond. Parabraham et al. (785) found a 63 to 93% reduction in BOD in a laboratory experiment over a 12-day retention time utilizing cultures of Chlorella and Clandemonas. Generally, with 400 pound BOD per acre loading, the reduction was in the range of 52 to 74%.

Olson et al. (777) studied lagoons treating dairy wastes in North Dakota and found that, in pond overloading, the sulfur bacteria (Chromatium) developed as a dominant flora with a loss in BOD reduction. This was generally true for the first several months after thawing of the lagoons in the spring.

Anaerobic Digestion

In anaerobic digestion, which is seldom used for dairy food plant wastes, initial attack is brought about by extracellular enzymes liberated by acid producing bacteria (11). Celluloses and starches are hydrolized with simple sugars and proteins are broken down to amino acids. The pattern of metabolism leads to the formation of acids which results in reduction in pH. Subsequently, a second group of bacteria develop which utilize the organic acids to convert them to carbon dioxide and methane. Metabolism of amino acids result in the liberation of ammonia which neutralizes a portion of the remaining acids. The second phase of digestion is known as the methane phase. Methane fermentation quickly lowers the excess acid and permits further degradation of the more complex organic compounds. The fatty acids remain essentially untouched until a healthy methane producing microbial population has been produced, then the fatty acids are degraded through beta oxidation.

Factors Affecting Microbiological Activity In Dairy Food Plant Wastes

The metabolism of the microflora of the various biological waste treatment systems have been investigated in some detail for municipal and industrial wastes (164, 209, 233, 235, 400, 607, 820, 1027, 1102), but only limited studies have been made concerning the microbial metabolism of dairy food plant wastes (3, 190, 469). Since the dominant microflora of dairy food plant waste treatment systems appear to differ from the microflora of municipal systems, there is a question as to whether the metabolic changes observed in municipal and other industrial wastes actually apply to those in dairy food plant waste treatment systems.

Adamse (3) investigated the growth characteristics of the major groups of bacteria in dairy wastes and activated sludge and found that the *Arthrobacter* species was the most active and efficient of the three types, with a generation time of 2.5 hours at 25°C. The generation time of *Pseudomonas* was 3.0 hours and *Achromobacter* had a generation of 3.3 hours in pure culture. Combination of these organisms in dairy wastes at 25°C showed different degrees of growth and dominance. The results are shown in Figure 37. Data reveal that the *Arthrobacter* grew slower in the mixed flora, but persisted over the entire incubation period, whereas the more rapidly growing *Pseudomonas* and *Achromobacter* species died out after 32 hours. The longer growth period of the *Arthrobacter* was related to the accumulation of polysaccharides which were available as a source of energy when the original exogenous substrate had been consumed. Neither of the other two species of organisms showed polysaccharide accumulation. The growth yield (mg cell dry weight produced from mg COD removed) is shown in Table 62.

Table 62 - Growth Yields of Three Representative Bacteria of Dairy Waste Activated Sludge with Artificial Dairy Waste as the Substrate

Microorganisms	Growth Yield (A)/(B)	Total Carbohydrate Percent Dry Weight
Arthrobacter species	0.46	51.7
Achromobacter species	0.38	8.1
Pseudomonas species	0.41	13.0

Oxygen demand immediately after feeding in artificial dairy wastes was found to exceed the oxygen supply (3) in experiments in batches wih well-aerated activated sludge. This caused a decrease in the dissolved and oxygen content of the material and a simultaneous decrease in the COD of the effluent. During the dissimulation of the substrate, acid

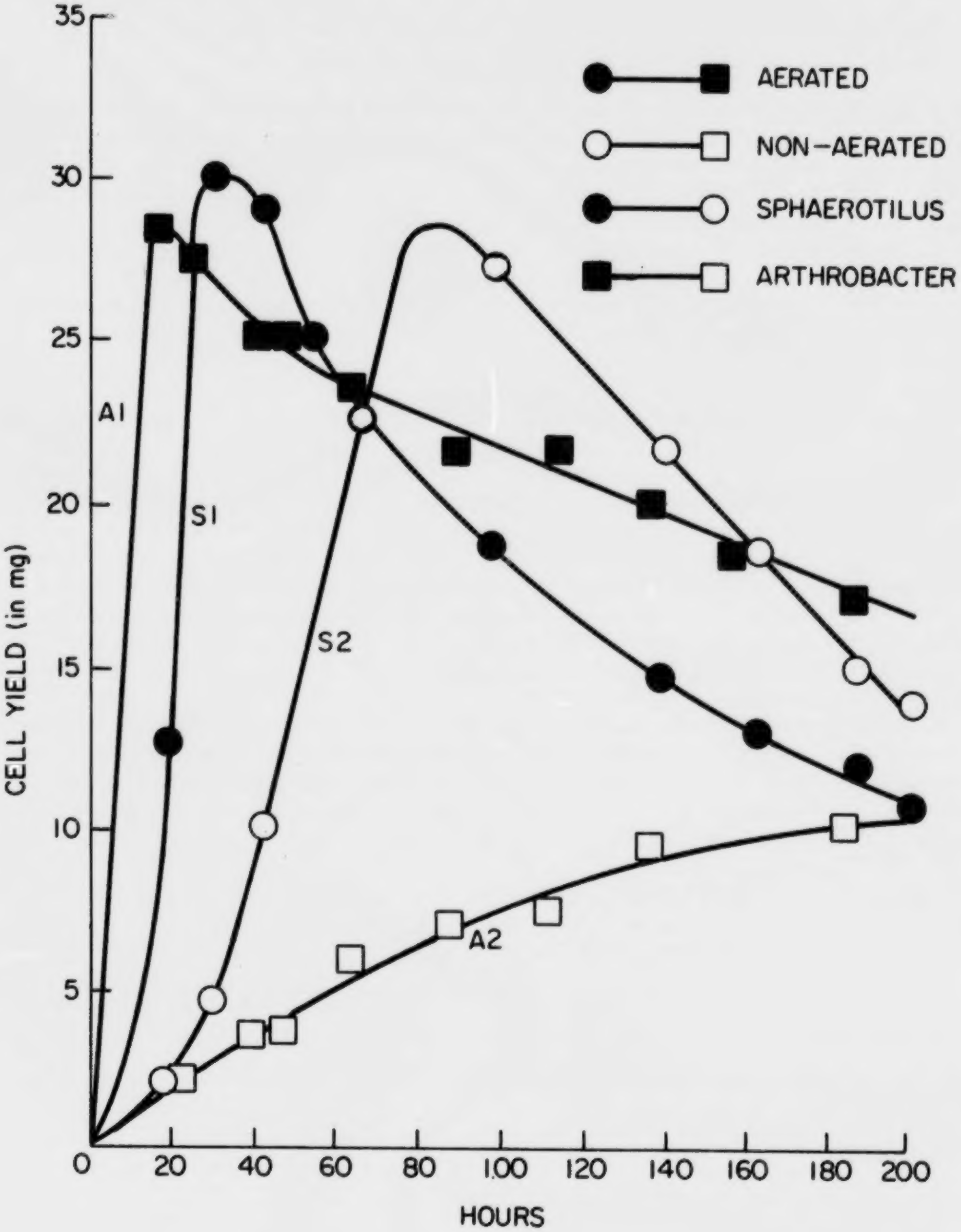


Figure 37 - Growth yield of a Sphaerotilus and an Arthrobacter species under well-aerated and nonaerated conditions.
Substrate: lactose, 0.1% and casamino acids 0.05%
Temperature: 25°C

intermediates from carbohydrates breakdown were excreted into the media causing a sharp drop in pH. This suggested that the oxidation of the carbohydrate fraction was limited even though adequate amounts of oxygen were supplied. The decrease in the pH proceeded more slowly when the dissolved oxygen content approached zero, indicating that acid formation was due to the activity of aerobic microorganisms. From the results that Adamse (3) obtained, the conclusion was reached that dissimulation of the protein fraction proceeded at a markedly lower rate than the dissimulation of the carbohydrate fraction (Figure 38). Protein degradation was less affected by low pH than lactose degradation. Decreasing the aeration rate diminished the sludge activity, whereas an increase stimulated the activity until the adsorption rate of oxygen became limiting. Even with small quantities of dairy waste, a drop in pH occurred. In studying the metabolism of sludge microorganisms, Adamse found that the drop in pH in the activated sludge shortly after feeding was due to the accumulation of acetic acid when dissolved oxygen was present and of lactic acid when dissolved oxygen was absent. Both acids were dissimulated after the substrate (lactose) had been exhausted. Lactic acid was assimilated more readily than acetic acid. The apparent dissimulation rate of artificial wastes was found to be optimal pH 6.5 of the activated sludge suspension. When lactose was added to the activated sludge approximately 10% was respirated, up to 50% was accumulated in polysaccharides, and the remainder was used for the synthesis of cell constituents and partly accumulated as intermediates in the sludge mass. The percentage of supplied oxygen expired was independent of the amount added or of activated sludge concentration, no correlation was found either between total carbohydrate content of the sludge oxygen uptake or the amount of oxygen supplied. The total carbohydrate content of the sludge depended upon the carbon-nitrogen ratio of the substrate supplied; a high ratio giving sludge with a high carbohydrate content. Supplying such a sludge with an excess of ammonium chloride and prolonged aeration markedly decreased the carbohydrates and also affected a decrease in the oxygen uptake rate.

Adamse (3) also studied the bulking of dairy activated sludge. Based on previous observations of the possible significance of Sphaerotilus and Arthrobacter, he conducted pure culture studies of these two organisms. Reduced oxygen supply, acidity, accumulated storage compounds, and the discrepancy between the potential and actual carbon-nitrogen ratios of dairy wastes were the main factors stimulating the relative growth of Sphaerotilus natans, and, in these studies, were responsible for bulking. Alteration of the nutritional conditions (Table 63) caused improved growth of desirable bacteria (mainly Arthrobacter-like organisms) and led to a pronounced suppression of Sphaerotilus natans with settling properties of the activating sludge being restored. The additive that had the greatest effect was lactate. Decreasing the actual carbon-nitrogen ratio by adding ammonium-chloride along with the dairy wastes favored the activated sludge growth and tended to minimize the Sphaerotilus. The characteristics of Sphaerotilus and Arthrobacter can

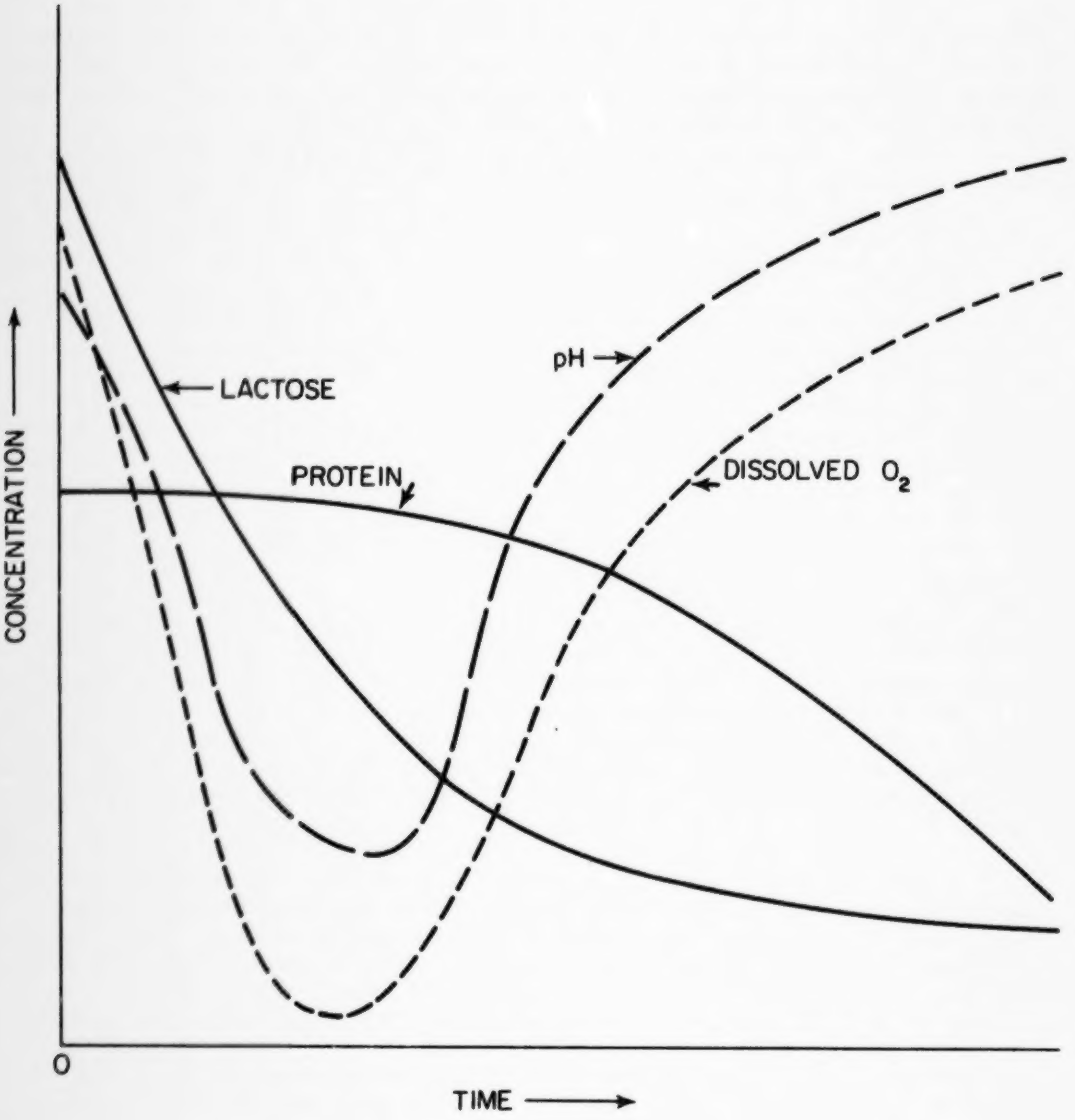


Figure 38 - Diagrammatic representation of changes in lactose, protein, pH and dissolved oxygen during activated sludge treatment of dairy food plant waste water. Adapted from Adamse (3)

Table 63 - The Effect of Added Substrates on Settling Properties of Activated Sludge

Suspension	Substrate	Settled Sludge Volume (m/ℓ)	Sludge Dry Weig[illegible] (g/[illegible]	Dry Weight Minus Ash (g/ℓ)	Sludge Volume Index	Corrected Sludge Volume Index	Remarks
1	Blank	672	4.80	3.46	140	194	No growth
2	$CaCO_3$	472	7.43	4.73	64	100	No growth*
3	Dairy waste	616	5.89	4.23	105	146	Growth
4	Dairy waste + NH_4Cl	800	8.24	6.70	98	119	Selective growth
5	Ca-acetate	372	7.34	4.85	51	77	Selective growth

*The increase of the sludge dry weight minus ash compared with the blank cannot be explained.

be characterized as follows:

(a) *Sphaerotilus* grows at low oxygen tension, whereas the growth of *Arthrobacter* is poor under such conditions. In well-aerated cultures, the growth rate of *Arthrobacter* exceeds that of *Sphaerotilus*.

(b) Both types of microorganisms are able to accumulate storage compounds when a proper substrate is supplied (high carbon-nitrogen ratio).

(c) *Arthrobacter* readily utilized inorganic, as well as organic, nitrogen compounds, whereas Sphaerotilus grows much better with inorganic than with organic nitrogen sources.

(d) Acetate is a more favorable carbon source for *Arthrobacter* than for *Sphaerotilus*.

(e) Both types of microorganisms are assumed to utilize accumulated storage compounds for growth when the exogenous substrate has been consumed and the nitrogen is still available. This is supported by the observed decrease in total carbohydrate content for *Arthrobacter* when pretreated with excess ammonium chloride.

The issue of nutrient balance has been raised repeatedly in respect to dairy food plant wastes even though calculation show a C:N ratio of 19.5:1 for milk and a BOD:N ratio of 25:1 for whey, which compare favorably with the 20:1 BOD:N ratio suggested for good operation of biological treatment systems. Adamse (3), however, discusses the discrepancy between calculated BOD:N or C:N ratios in milk and the "available" BOD:N or C:N ratios. Since protein is only slowly assimilated, the available ratio may be quite low. Adamse (3) and others (516) have reported the advantage of supplementing dairy food plant wastes with ammonia nitrogen. However, other investigators have failed to show an increased efficiency in BOD reduction through the addition of nitrogen. All of the dairy plants with activated sludge treatment plants to which site visits were made stated that they had tried and abandoned the use of nitrogen supplementation because of the lack of any beneficial effect in actual practice. Enzymes have been suggested to improve treatment efficiencies, but no definitive evaluation of their effect has been reported. Since there is some evidence that some of the microorganisms have to degrade amino acids through the citric acid cycle before they can be used, the enzymatic degradation of proteins to amino acids may not be of value.

SECTION IX

WASTE TREATMENT METHODS

Each waste treatment method will be reviewed relevant to analysis of literature laboratory scale data to develop information on available principles, a compilation of loading and performance characteristics of waste treatment plants reported in the literature, and an examination of the information in respect to principles and industrial observations.

ACTIVATED SLUDGE TREATMENT

Activated sludge treatment of dairy food plant wastes involves an initial aeration process followed by a clarification step and a return of varying amounts of the active biomass (sludge) to the aeration tank. Much of the basic information available on the treatment of dairy food plant waste water has been obtained by use of the activated sludge process.

U.S.D.A. Research

A major share of the early research on activated sludge treatment of simulated milk plant wastes was conducted by the U.S.D.A. in response to questions raised in 1947 and in later years by the Task Committee on Dairy Waste Disposal of the Dairy Industry. This work contributed significantly to sanitary engineering at the time, was widely disseminated and remains the most familiar and basic work in this area of waste treatment. For these reasons this research will be examined closely before consideration of the design parameters currently desired.

Methods: Initially Porges and Hoover (468) based their study on the earlier work of Bloodgood (174), an unpublished study by Eldridge (1948) and Trebler and Harding (1133-4). They followed COD, lactose sludge formation (reducing sugar by lead acetate), protein nitrogen (biuret reaction of ppt protein) and non-protein nitrogen in fermentation by B. polymyxa, Sacchromyces fragilis and small rod from cow manure. A wide difference in rate of proteolysis was observed over 97 hours.

Continuous Aerated Study: Hoover and Porges (468) used a continuous air flow of 0.75 to 0.85 volume/minute. Centrifugal separation was used in the laboratory experiments and was suggested for possible use in industrial waste disposal systems. They found that a 0.1% reconstituted skim milk (COD $\approx$ 1050 ppm) produced 580 ppm of a light nonsettling sludge in a laboratory scale well-mixed aerator.

They also reported that "dairy wastes" (0.1% skim milk) were very rapidly assimilated by microorganisms in aerated systems. No kinetic constants were presented; but 89 to 98% removal of COD was said to have been achieved in 9.5 to 20 hours in a pilot-scale, well-mixed, activated sludge system. The authors made a materials balance on the organic solids in the feed, centrifugal effluent and biomass based on COD values. Lactose COD had been found to be 1.12 times the biomass and protein COD to be 1.42 times the biomass. About 45 to 50% of the COD solids fed appeared in the biomass while about one-half of COD solids fed disappeared and were apparently oxidized for cell energy.

Porges, et al. (836) used 0.1% reconstituted dried skim milk as a model for milk waste. This system was said to resemble the soluble constituents of milk left in solution after the coagulation of the fat during the aeration process.

The authors employed the Eldridge et al. method for COD determination (unpublished) which gave: (a) good agreement between COD and 20-day BOD for fresh wastes but not for fermented wastes and (b), no comparison between 60% COD and 5-day BOD. Their conclusion was that "the fairly homogeneous character of dairy wastes permits the use of a chemical method, with satisfactory results." As reported earlier in this report, COD is not in general use by industry today.

Assimilation of Dairy Wastes

Hoover, Jasewicz and Porges (476) made a manometric study of oxygen uptake at 30°C for 0.1 and 0.3% skim milk solids, or ammonium sulfate supplemented casein and lactose. The seed culture was sludge from a successful market milk plant activated-sludge treatment system.

The oxygen uptake was approximately exponential after a lag of up to an hour for each of these subtrates. The seed culture had been maintained two or seven days on skim milk in a laboratory scale flow aerator. The oxygen uptake was more rapid, nearly linear, and still rapid at the end of six hours for fresh sludge. Their data for the oxygen consumed by the casein, ammonia sulfate-supplemented reconstituted lactose, fractions of 1% skim milk powder and 500 ppm of sludge, indicate that the net oxygen required by each fraction were nearly equal with k_{10} values on the order of 0.08 to 0.16 hour^{-1}. When the consumption of each individual organic component was added to the consumption for sludge alone, the oxygen consumption rates was within experimental error for that of skim milk and sludge.

The BOD_6 hr/COD ratios for supplemented lactose, casein, and skim-milk powder were found to be about 0.37-0.43, 0.37-0.40 and 0.32-0.37, respectively. These ratios did not change noticeably with a change in sludge activity in these experiments. After six hours, the fraction of BOD remaining in lactose and casein were not detectable in the separated supernatant and less than 10% of the skim milk remained "unoxidized." The substantial disappearance of COD from the (centrifuged) effluent liquor in this example seems to have lead many readers to the conclusion that milk plant wastes are "easy" to treat. The ratios of CO_2 produced to O_2 consumed during the six hours test were found to be approximately 1.03 to 1.06 for supplemented lactose, 1.0 for casein and 1.03 for skim milk solids.

Aeration as a Partial Treatment: Hoover, et al. (477) investigated the feasibility of using the process of centrifugation following the aeration of dairy wastes, which was suggested in an earlier paper (468). Over a four-hour period, four volumes of milk fractions were added to the one volume of sludge from an earlier run which remained in an aerated vessel. The temperature was 30°F, the aeration rate was one volume per minute.

Simulated wastes of 0.1% skim milk, 1.0% skim milk and 0.5% skim milk (COD's of 1050, 10,500, 5000; BOD$_{20}$ of 1060, 10,600, 5000, BOD$_5$ of 640, 6400, 4300) showed substantially reduced concentrations in about six to eight hours after the start of the fill operation. After 16 to 18 hours total waste show reductions of 60, 55 and 55% COD; 73, 71, and 58% BOD$_{20}$, and 80, 75, and 75% BOD$_5$ for the 0.1% and 0.5% skim milk, respectively. The supernatant obtained by centrifugation showed more substantial reductions (89, 93, 94% COD basis, 92, 93% BOD$_{20}$ basis, and 92, 94, 95% BOD$_5$ basis). The total effluent had greater reductions of BOD, especially BOD$_5$, than for COD. All the centrifuged effluents had 89 to 95% reduction in concentrations. This suggests lower rates of biological oxidation and perhaps lower availability of waste in the biomass following the contact period. No provision was made to prevent nitrification. The higher concentration milk, in preliminary studies 2.5 and 5% whey solids, showed poorer reduction efficiencies than the dilute solutions. In the case of 5% whey solids the removal from the centrifuged effluent was reported to be much more incomplete. Light, finely divided flocs were reported and were attributed to the mechanical action of the stirring blades in the fermenter.

The Rate of Oxygen Utilization: Hoover and Porges (475, 472) studied the depletion of O$_2$ polargraphically for liquor containing 500 ppm aerated sludge and 0, 25, 50, 100, or 1000 ppm of skim milk solids.

A plot of oxygen concentration versus time, and a graph of reaction rate, i. e., the time required to deplete the dissolved oxygen level to 0.5 at 1000 ppm skim milk solids/time of selected concentration were shown. The authors observed that there was a "rapid and relatively constant rate of oxidation of skim milk solids" and that the "rate of assimilation...is essentially constant above 1000 ppm of added skim milk "solids." (This concentration of waste corresponds to a ppm waste/ppm vol SS of 0.2 or a 0.21 ppm COD/ppm ml vol SS solids.) The uptake of nutrients has been said to be rapid, the fraction of substrate associated with the biomass undoubtedly increased somewhat over the 10 minutes of the experiment.

The initial DO depletion rate of 0.37 ppm/minutes (22 ppm per hour) at 100 ppm skim milk solids/500 ppm sludge and a DO of 3 ppm upon contact of load and cells was noted to present a substantial air supply problem. Nonetheless, in discussion, the authors suggest a lower rate; the calculated average rate over a six-hour "assimilation" period to be supplied to a conventional activated sludge treatment of a milk waste, for example, 1000 ppm of skim milk solid.

A plot of the difference between the O_2 consumed by waste and sludge and that for sludge alone is shown in Figure 39 for different concentrations of skim milk solids. Here the O_2 depletion associated with assimilation is seen to be curvilinear; perhaps either first-order or Monod kinetics would fit this limited data. Further, the rate of depletion decreases appreciably for the lower waste loads before the 0.5 ppm threshold pointed out by the authors. The initial O_2 depletion rate, associated with assimilation, is also seen to depend upon the loading rate. This is approximately a 0.10 order reaction with respect to ppm of skim milk solids.

It would appear useful to extend these studies to the other fractions and combinations of milk products and milk plant waste especially at the higher concentrations, and waste/sludge loadings often encountered in operating dairy waste treatment facilities.

Overall Equations of Syntheses: Hoover and Porges (469) developed approximate chemical equations to represent the apparent fate of carbon, hydrogen, oxygen and nitrogen in the complete oxidation and/or cell "synthesis" of ammonia-supplemented lactose, casein, and skim milk, and oxidation of a well-aerated "sludge." These calculations were based on the empirical composition for "casein," $C_8H_{12}N_2O_3$ and/or the sludge, $C_5H_7NO_2$. Further assumptions were that the oxidation of lactose was assumed complete, that the oxidation of casein followed carbohydrate utilization so that in cell "synthesis" from casein one-half of the available nitrogen was released as ammonia.

The ratios of CO_2 produced to O_2 consumed could be estimated from these relationships using the BOD_6 hr/COD ratios reported earlier (476) as estimates of the fraction of the waste which was "oxidized." The agreement between estimated and observed CO_2/O_2 ratios for this earlier data was within experimental error.

Eckenfelder (312a) was able to calculate a vol SS_{BD}/g COD ratio of 0.43 for supplemented lactose from the combined results of both papers. Similarly, g/vol SS/g COD of 0.43 for casein and 0.50 to 0.56 for skim milk may be calculated.

Endogenous Respiration

Hoover, Jasewicz and Porges (472) studied the CO_2 production, and indirectly, the O_2 consumption of dilute skim milks with about 500 ppm sludge, and of sludge alone. The O_2 data were compared from the experimental observation that the ratio volume CO_2 produced/volume O_2 consumed was approximately 1. They found that an aerated mixture of 1000 ppm of skim milk waste and 410 ppm of sludge produced a maximum oxygen requirement of 83 ppm/hour which after several hours reduced to about 10 ppm/hour. This is much higher than the 22 ppm maximum found in earlier unaerated depletion studies (Hoover and Porges, 1952).

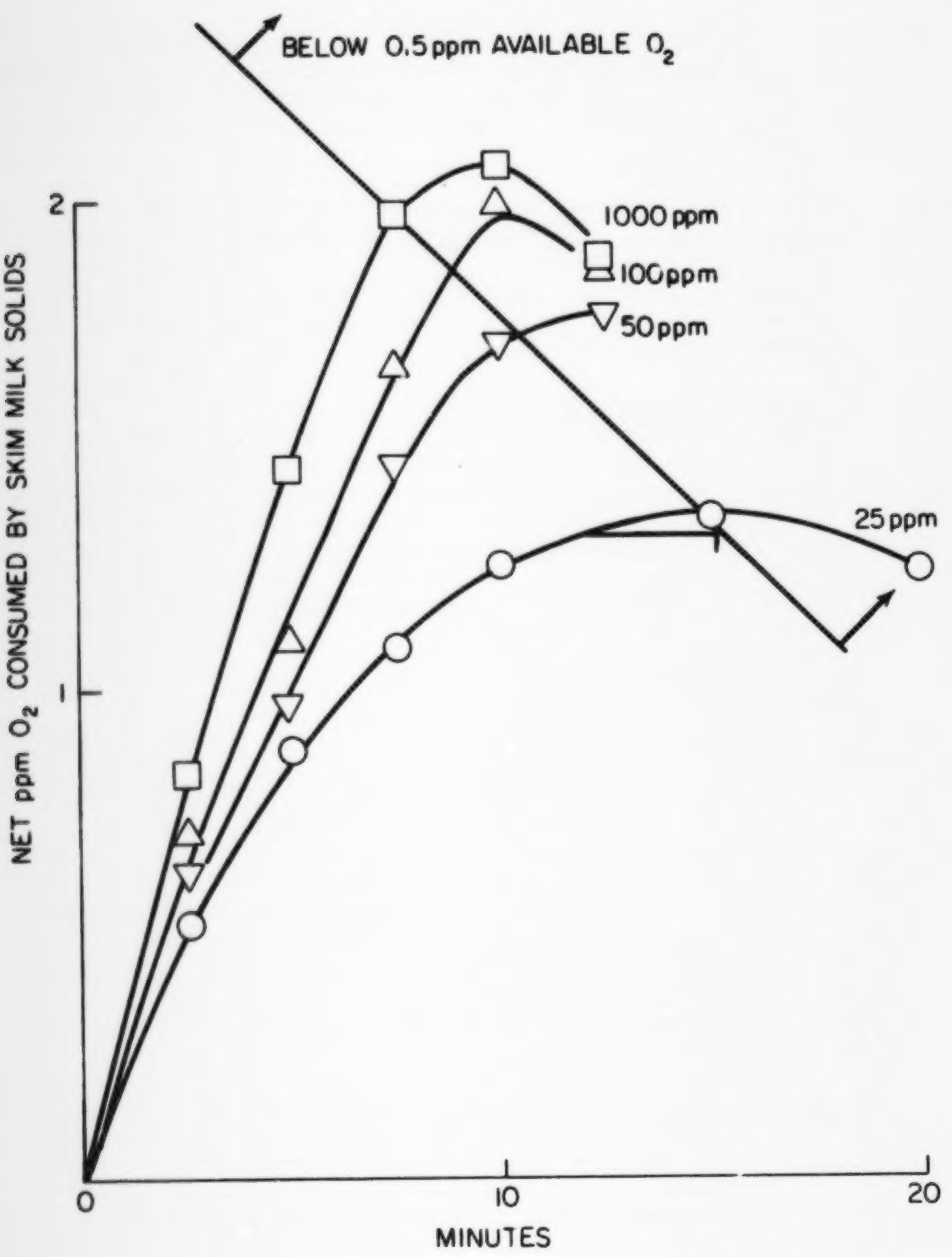


Figure 39 - Oxygen depletion in activated sludge treatment of varying concentrations of skim milk solids

The oxygen requirements of unfed sludge has an initial value of 14 ml/g sludge hour to 4 ml/g sludge hour (1 ml O_2 = 1.43 mg). A reduction in waste concentration to 800 ppm and sludge solids to 76 ppm reduced the maximum O_2 demand to 45 ppm/hour and, after several hours, to 4 ppm O_2/hour.

Hoover, Jasewicz and Porges also pointed out that a 1000 ppm skim milk solids waste having a BOD_5 of 640 and COD of 1200 would require 40-45 ppm O_2/hour before treatment (fill and draw). After treatment, the O_2 requirement would be less than 4 ppm. This would correspond to a reduction of more than 90%. An earlier paper had indicated that such a process is normally 75 to 80% efficient based on BOD.

Failure of Na_2NO_3 as a Source of Oxygen: Porges, et al. (837) found that sodium nitrate, at a level sufficient to supply one-half the calculated COD, failed to markedly increase the activity of 500 ppm sludge for treatment of 10,000 ppm skim milk, 5000 ppm lactose or 3500 ppm casein. In fact, odors like those found under anaerobic conditions were detectable for the unaerated portion of their studies. They concluded that "sodium nitrate has no value as an oxidizing agent in disposal of dairy wastes, especially for emergency purposes when oxidizing agents must be added to avoid odors."

Reviews

The research studies by the USDA group were periodically restated by later publications of symposia papers and in reviews of overall progress. These reviews began in 1952 with the USDA publication by Hoover and Porges entitled, "Treatment of Dairy Waste by Aeration," Hoover (466), "Biochemical Oxidation of Dairy Wastes – a Review," Porges, Jasewicz and Hoover (833), "A Microbial Progress Report – Aerobic Treatment of Dairy Wastes," and continued with Porges (826) "Waste Treatment by Optimal Aeration – Theory and Practice in Dairy Waste Disposal," Hoover, Jasewicz, and Porges (474), "Aerobic Process for Dairy Wastes," Porges, Jasewicz and Hoover, "Principles of Biological Oxidation," Ch. 1-3 in McCabe and Eckenfelder (469a) and Porges (625) "Bio-Oxidative Treatment of Dairy Wastes."

An Interpretation of the BOD Test: Hoover, Jasewica and Porges (475) offered an interpretation of the BOD test in terms of endogenous respiration of bacteria in dilute reconstituted skim milk.

They noted that published data on the endogenous respiration of common organisms at temperatures close to 20°C had QO_2 values averaging about 10 and ranging from about 4 to 25 $\mu\ell$/mg cells per hour. This rate corresponds to a reduction in cell mass of nearly 1% per hour (1 mg of ash-free cells from skim milk had required 1.42 mg O_2 or 993 $\mu\ell$ O_2.) They further showed that the first BOD reaction proceeding at a normal rate of $k = 0.1$ day^{-1} would correspond to 23% per day, or 23/24% per hour.

They found that 64 to 77% of the soluble organic matter in skim milk added to seeded BOD bottles was removed in five hours and almost completely removed within a day. Oxygen requirements averaged 30 $\mu\ell$/mg-hr over the first five hours then decreased to about 6 $\mu\ell$/mg-hr for the 24- to 120-hour period. In an aerated system containing 450 ml of acclimatized sludge and 1000 ppm of skim milk, the Q_{O_2} averaged 72 $\mu\ell$/mg-hr over the first quarter day decreasing to slightly over 3 $\mu\ell$/mg-hr for the third day, and to about 1 $\mu\ell$/mg-hr at the end of 20 days. The unfed sludge itself had Q_{O_2} values of 7.5, 5, and 1.7 at the same points in time.

The authors first treated their data as if the oxygen depletion was first order, then used a Thomas plot (1950) of $(t/O_2 \text{ demand})^{1/3}$ versus time. The graph was nonlinear indicating that a first order equation did not completely fit the first 12 days (or approximately 90% of the BOD). From the data for the first five days one may obtain the following approximate equations for the oxygen demand, y, at time t, days of $y = L(1\text{-}10^{-kt})$ where:

L = 806 ppm for substrate and sludge
= 186 ppm for sludge, and

k = 0.29 day^{-1} for substrate and sludge
= 0.19 day^{-1} for the sludge.

In an earlier study they had found that a 0.1% reconstituted skim milk would have a BOD of about 640 ppm as contrasted to the 620 net ppm found here. The 180 ppm BOD estimated for the sludge is approximately 49% of the COD of the original sludge. The rate constant, k, of 0.17 for the sludge is much higher than the 0.1 the authors expected, and was said to be invalid because of the failure of the first-order approximation to predict the O_2 consumed in 12 days (it was 14.5% low).

Their plot of oxygen consumption for both the waste and sludge, and unfed sludge systems show a strong linear component increasing with time, so it is not surprising that the data did not fit a simple first-order reaction model. In fact, their data plot suggests that:

$$O_2 \text{ consumed} = ct + L_1(1\text{-}10^{-k_1 t}) + L_2(1\text{-}10^{k_2 t})$$

and for 0.1% reconstituted skimmilk and sludge:

c = 12.5 ppm/day

L_1 = 375 ppm, k_1 = 0.131/day

L_2 = 360 ppm, k_2 = 1.54/day

and for unfed sludge

$c = 7$ ppm/day

$L_1 = 135$ ppm, $k_1 = 0.19$/day

The L values are of the order we might expect of the lactose, protein and sludge fractions from their work. The rate constant k_2 is of the order of, but smaller than, the rate of O_2 consumed during the "assimilation" period for their earlier study of the O_2 uptake of the casein and ammonium sulfate-supplemented fractions of their skim milk waste. The first rate constant k_1 is nearer their expected value and is well within the range reported from the literature. Nonetheless, separate kinetic data for components are needed to accurately interpret the above relationships.

After the Thomas plot, the authors used plots of O_2 consumption versus log time, an emperical approach at that time proposed by Osford and Ingram, (1953). Alinear curve was found for sludge with substrate and a nearly linear curve for unfed sludge. Upward breaks, such as Osford had found for a system with nitrification, are not present. The authors suggested that the log time relationship is like the proteolytic digestion of casein (Hoover and Kokes, 1947).

Kinetics: Hoover, Jasewicz, and Porges (473) reported the COD rate of "purification" and "oxidation" of 1000 ppm sludge and milk fractions in a 20-liter vessel at 30°F.

In one experiment, the lactose and COD removal from 1000 ppm skim milk were found to be as high as $k_{10} = 48$ and $k_{10} = 30$ days^{-1} for purification of lactose and COD, respectively. The k oxidation of COD for this system was 1.8 day^{-1}. Their values for 1000 ppm were of the same order as unpublished pilot plant studies at Pennsylvania State University but were several fold higher than computed estimates from their earlier data. They noted that their values were lower than those reported by Gellman and Heukelekean (390) for a shaker flask system at 20°C, and a BOD basis.

Rates for 1000 ppm of reconstituted dried whey presumably "sweet" whey were determined in one experiment. The pruification and oxidation rates were nearly the same as for skim milk. They said that "whey is oxidized at a comparable rate to that of milk, if sufficient nitrogen is present," and added that in subsequent experiments that "it was necessary to add nitrogen for the oxidation of whey to proceed satisfactorily." The "pseudo" first order rate constants were determined from half-lives, although the reactions were said to depart from first order behavior.

Apparent Storage of COD: Temperature Effects: Porges, Jasewicz and Hoover (834) had observed that the ratio of purification and oxidation rates for skim milks were higher than would be expected from the ratio of moles of oxidizable carbon to moles of oxygen consumed. The latter relationship developed from a gross stoichiometric balance over a six-day aeration time (469). (A still earlier study (476) had shown casein and ammonium sulfate supplemented lactose to have the same oxygen consumption rate). They interpreted this difference between "purification and oxidation" rates as evidence of COD storage in the cells.

Experimentally, they used 1125 ppm skim milk COD and 1000 ppm sludge solids in small aerated vessels at several different temperatures. A COD balance was used to ascertain the amount of COD stored. The COD removed was determined by titration, and O_2 consumption was calculated from CO_2 evolved assuming the ratio quotient of 1 found earlier. The expected value of cell COD was calculated from the stoichiometric equations referred to above; the stored COD was said to be the COD removed minus the stoichiometric amount calculated to be used for new cells and energy.

More than 90% of the COD fed was removed within five hours at all temperatures except at 2°C. At this temperature (i.e., 2°C) only one-half the COD fed was removed in 20 hours; hover, 90% of the one-half was removed in the first five hours.

The data are not sufficient to obtain more than crude estimates of the O_2 consumption rates; k_{10} values calculated by the method of moments for the first three hours (Fair, Geyer, and Okun, 351) are 0.3, 0.5, 0.4, 0.2 hours^{-1} at 2, 10, 20, and 30°F respectively. At the end of 20 hours the oxygen utilized is in the ratio 1, 2.1, 3.5, and 5.7; however, the influence of higher oxygen requirements appears to overcome the lower estimated k at 30°C.

The COD "stored" rose within three hours to a maximum of 34, 49, 60, and 63% for 2, 10, 20, and 30°C, respectively, then began decreasing with the most dramatic decrease at 30°C. The storage of COD in the form of a glycogen-like material was said to reduce the nitrogen content of the sludge from 12.4% N to 7.5%. This estimate was based on the premise that the sludge composition before COD pickup was $C_5H_7NO_2$ as it had been after an unspecified aeration time for 1000 ppm skim milk and 500 ppm sludge (476, 469). Still this seemed to be below the BOD/N ratio recommended by Helmers and coworkers (446), for the authors converted this criteria to a COD/N ratio, for this system, of 28:1 and assumed that about five-eighths of the COD were converted to cell mass; and that since nearly all of this was carbohydrate, then only about 6.9% nitrogen would be required.

Pilot Scale Studies: Kountz (593) reported on his research on pilot-plant and fill-and-draw full scale systems for the USDA. His designs were based on the earlier research by Hoover, Porges and associates but for 250 pounds of sludge/100 pound BOD_{20}, which were higher levels than used in most of the laboratory studies. From these experiences he reports volumes of 0.8 ft^3/pound for settled sludge.

He also noted three operational problems, cessation of bio-oxidation attributed to whey presence, foaming, and floc break-up. "Whey" is said to cause treatment to cease because of nutritional deficiency which can be made up by adding one pound of ammonia nitrogen per 100 pound of whey solids.

"Foaming of the aeration tank is a nuisance which is not fully understood as to its cause or frequency of occurrence." Excessive agitation or aeration was said to be one of the causes.

Some floc break-up was believed to occur in the Pemberthy ejectors, with little break-up attributed to the "hot-coke" size bubbles in the bulk of the tank.

Whey Study: Jasewicz and Porges (516) reported on the treatment of dilute whey (1000 ppm) in the presence of sludge (2000 ppm) in an aerated stirrer-agitated 12-liter vessel at 30°C over a period of 96 days. Air was supplied at a rate of $1\frac{1}{2}$ volumes per minute. One vessel contained reconstituted dry whey, presumably "sweet" rather than "acid" whey, and the other contained added nitrogen (NH_4OH) as well as whey. The COD/N ratios of the waste without sludge were 50:1 and 30:1, respectively.

Both systems showed removal of substantially all the COD from the filtered effluent, and a pickup by the sludge, in about one-half hour with nearly complete depletion of the added COD in the sludge within 24 hours. Some sludge buildup occurred. For sludge acclimatized on whey, nitrogen supplementation reduced the time for the sludge COD to return to its initial level of 60 to 16 hours. For 96-day (whey-acclimatized) sludge the times were 60 and 26 hours, respectively.

Sludge oxidation was 15% within 24 hours compared to cited values of 23% for skim milk sludge and pharmaceutical sludge, 10% for municipal sewage and 7% for pulp and paper acclimatized sludges. The skim milk sludge had about 21% sludge oxidation and the whey sludge about 19% at 72 hours aeration, but was not significantly influenced by nitrogen supplementation. The results of moment analysis of their curves for sludge oxidation are tabulated below.

	Whey Alone		Whey and Nitrogen	
	Fresh	Acclimatized	Fresh	Acclimatized
k, day^{-1}	0.26	0.13	0.58	0.37
% oxidation	26%	31%	21%	21%

The estimated sludge oxidation rates show reduced activity of whey acclimatized sludge and greater activity with added nitrogen, as indicated above. The estimated ultimate percent sludge oxidation are not in agreement with experimental observation that the sludge concentration more than doubled over the 96-day period.

The 96-day sludges settled "very poorly" and had nitrogen contents of only 4.0 and 3.2% (with and without supplementation) contrasted to 11.3% initially and the "accepted 7% minimum."

The authors referred to unpublished experiences at Pennsylvania State University where treatment of whey and dairy waste was successfully made possible by the addition of ammonium sulfate in the ratio 100 pound/ 5000 pound whey in COD:N of 17:1. In an accident where $NH_4(SO_4)_2$ was not provided, excessive loading occurred immediately.

Whey: COD and Solids Balance: Porges and Jasewicz (831) made a COD and solids balance on a laboratory fermentation of whey, and whey with supplemental nitrogen. The balance was begun on the 35th day of the study described earlier (516) when it became evident that sludge increase, longer settling times and sludge loss in the effluent was occurring. The balance was made in the next 61-day period. About 75% of the COD fed the system appeared to have been oxidized. When the effluent was clarified by filtration the system removed an average of about 97% of the COD fed. They estimated that the sludge oxidation rate was about 5% per day. The sludge build-up may be estimated to be about 3 to 4% per day. Both estimates are made on the assumptions that a whey treatment system like that for skim milk, will convert about five-eighths of the available COD to cell COD and that no sludge is lost in the effluent. This sludge oxidation rate is comparable to the 5.5% reported by Kountz and Forney (594) for skim milk, but substantially less than that reported in the authors earlier studies (472). In practice the net sludge build-up was only about 0.4 to 0.6% per day.

They suggested that with only 10 units of whey COD per 100 units of sludge COD and a sludge oxidation rate of 6.3% per day would give equilibrium with negligible sludge accumulation.

Supplementation by NH_4OH seemed to be of no value in this experiment. In fact the supplemented whey system and a somewhat larger sludge build-up and sludge loss in the effluent.

Metabolic Energy Balances: Kountz and Forney (594) re-examined the COD balance for a continuous laboratory scale plug flow skim milk system. The earlier USDA sponsored study (471) had been for a laboratory scale, intermittent feed system in which carbohydrate build-up as polysaccharides (813) had been observed.

The pH of the entering skim milk was 7.2. The temperature of the ambient was 75°F, the oxygen level was greater than 2.0 ppm, and the feed rate was 0.2 ppm. The sludge return rate was 0.8 ppm, the detention times were 5 hours (1 hr. each) in aeration tanks $1\frac{1}{2}$ hour of clarification and sludge return and one hour of sludge aeration. Thus the feed milk solids concentration was about 690 ppm and the loading rate 41 pounds of skim milk solids 1000 ft^3. Later the BOD_5 was said to be 600 ppm.

The nitrogen content of the sludge was reported to be 8.5% close to the experimental value of 7.5 of Porges et al. (834) for the period of maximum COD "storage" but less than the 12.4% reported by Hoover and Porges (469) after an unspecified contact-aeration period.

The CO_2 evolved in each vessel was measured and interpreted as O_2 on the presumption that the respiratory quotient, g O_2 used/g CO_2 evolved was 1.0 (832). This oxygen profile was interpreted to indicate that oxygen requirements for purification assimilation energy, new sludge formation and endogenous respiration were 18, 45, and 37%, respectively. Nearly 80% of the purification O_2 requirement occurred in the first vessel (1 hr) and the remainder in the second vessel.

Hoover and Porges (469) had proposed that three-eighths of both the lactose and the protein were oxidized for energy and that no excess gas in the form of NO_3 was produced from protein.

Since this earlier prediction did not satisfy the O_2 distribution of this experiment the authors worked with the overall oxidation-synthesis equations to obtain a better estimate. They proposed that three-eighths of the protein be oxidized but that three-fourths of the carbohydrate be oxidized for energy. Three-eighths of the carbohydrate was to be oxidized in the "purification" step and another three-eighths in the assimilation-new sludge formation step. The sludge formed was only 70% of that projected earlier (469) and 30% of the NH_4 released by protein degradation was free for oxidation to NO_3 which would appear in the effluent. No free NH_3 was observed in this or the USDA studies.

The sludge formed was about 31% of the weight of dry skim milk fed, and 58% of the ultimate oxygen demand. Earlier studies by Hoover and Porges had indicated the sludge formation was experimentally about 52% of the weight of skim milk fed (469, 476) as compared to a prediction 58.8% (469).

Earlier work by the authors had indicated a k-value for the influent of 0.27 day^{-1} and, in this study, a k-value for the effluent of 0.05 day^{-1}. The efficiency on a BOD_5 basis was about 98% and on a ultimate BOD basis was about 97%.

In the conclusions, the authors reported that 20 to 25% of the new sludge (which in turn was 58% of the BOD_5) is not readily oxidizable; that the build-up of this fraction is 0.6% per day; that the actual endogenous loss was 2% of the total sludge mass per day, and that the equilibrium weight of the sludge is 14 times the effluent weight per day.

Summary

In discussion of the practical implications of their work, Hoover and Porges (469) in 1952 planted the seed for what have become accepted generalizations with respect to dairy waste treatment.

These generalizations are:

1. The treatment of dairy waste can be inferred from laboratory results for 1000 ppm reconstituted skim milk solids.

2. For assimilation (of 1000 ppm skim milk solids)

    a. The g COD/g solids ratio is 1.2.

    b. Oxygen requirements are three-eighths (0.375) of the ultimate COD.

    c. Assimilation is essentially complete in 6 hours. Further, the rate of assimilation is 167 ppm waste/hr-500 ppm sludge.

    d. Oxygen supplied at the average rate will be sufficient (0.075 lb/hr).

    e. The rate of oxidation is constant above 0.5 ppm dissolved oxygen.

3. For endogenous respiration

    a. Oxygen requirements are five-eighths (0.625) of that for complete oxidation.

    b. The grams cells/grams waste ratio is one-half (0.52).

    c. Biological oxidation of the cells (500 ppm) requires 30 hours. (Elsewhere the authors report 60 or even 160 hours (Porges, Jasewicz, and Hoover (833)). i.e., 0.62 to 3.3%/hr with 1%/hr appearing in USDA Handbook No. 176). Thus the oxygen requirements could vary from 0.025 to as low as 0.005 lb/hr, the average value for the treatment process.

These generalizations were, in large measure, incorporated in USDA Handbook 176. Subsequent investigations by the authors (833) brought out the fact that organic solids (≈83%) rather than total solids should be in the above rules of thumb. The change in the endogenous respiration rate noted above, and a sludge volume of 0.8 ft^3/lb, (Kounz, 586) gave the authors a better understanding of the biological processes.

It is unfortunate that the frequent reporting by this very active group of investigators at a time of industrial need has codified the results of a relatively few experimental trials of these pioneering investigators. The direct use of these generalizations to represent waste from a "dairy" plant in USDA Handbook 176 ignores the presence of free and emulsified fat; conveyor and machine lubricants; cleaning compounds including acids, bases, and surfactive agents, chloride ion, whey wash water and even whey which has frequently resulted in poor and variable performance of biological treatment systems.

BOD and COD Kinetic Data

Literature data for the kinetics of reduction of BOD or COD in dairy waste fractions by activated sludge are shown in Tables 64 and 65.

Most of the investigators have used the following equation to describe the purification or oxidation steps

$$\frac{dL}{dt} = -2.3\ kL \qquad [11a]$$

or

$$L = L_o 10^{-kt} \qquad [11b]$$

where L and L_o refer to the remaining and initial BOD or COD at time, t.

The USDA investigators have shown that the "purification" reaction is dominant during the initial contact period and is nearly complete within the first one half to six hours (834a, 469, 827). This is the "assimilation" period required to "oxidize" a portion and transfer nearly all of the remaining waste to the biomass. This BOD or COD primarily associated with the biomass, was then presumed to be "oxidized" by subsequent biological processes of 30 or more hours (834a, 469).

At the time of these kinetic studies, the fraction of waste transferred to the biomass appeared to be a characteristic only of the composition of a waste, and all of the organic position of this biomass seemed to be biodegradable. Thus, activated sludge units were built and operated without sludge removal systems, and little or no data were reported regarding the fraction of waste which could be degraded.

In many instances the substrate for the oxidation process is the freshly-fed sludge immediately following the purification phase of treatment. The sludge concentration itself, in parts per million, gives some indication of the relative scale of BOD or COD to be removed in this process but the BOD or COD of this fraction is generally not given. The USDA workers have indicated that about seven to ten-sixteenths of the total oxygen required are needed during the so-called purification step (469,594).

The USDA investigators also suggested that the O_2 requirements during the five-day BOD test be interpreted as "oxidation." Thus the data for these and other workers in respect to BOD's of milk or milk

Table 64 - Pseudo First Order Rate Constant for Oxygen Consumption of "Dairy Wastes" k Days^{-1} in BOD Bottles or Shaker Flasks

Waste	Treatment System	Temp., °C	Waste Conc., ppm	Sludge Conc. ppm	Basis	k_1 Purif.	k_2 Oxidation	Reference
Whole Milk	Std. BOD	-	(five days)	-	BOD_u	-	0.09	374
Renneted Milk			(five days)	-	BOD_u	-	0.03	
Whey			(five days)	-	BOD_u	-	0.07	
Acid Milk			(five days)	-	BOD_u	-	0.06	
α-lactose	Std. BOD	-	(after lag)	m	BOD	-	0.06	1179
β-lactose		-	(after lag)	m	BOD	-	0.11	1 day lag for α
Galactose			-	m	BOD	-	0.05	2 day lag for β
Dextrose			-	m	BOD	-	0.10	
Sucrose			-	m	BOD	-	0.10	
Skim milk	Std. BOD	-	influent	a	BOD_5	-	0.27	594
			effluent	a	BOD_5	-	0.05	
Diluted "milk"	Shaker flasks	20	1300	500m	BOD	0.6	0.15	392
			1300	1000m	BOD	0.9	0.2	
			1300	2000m	BOD	1.2	0.25	
			1300	500a	BOD	0.7	0.35	
			1300	1000a	BOD	1.2	0.45	
			1300	2000a	BOD	1.5	0.6	
			1300	4000a	BOD	3.0	1.1	
			655	2000m	BOD	0.5	0.25	
			1310	2000m	BOD	1.2	0.25	
			2620	2000m	BOD	0.9	0.25	
			650	2000a	BOD	4.8	0.8	
			1310	2000a	BOD	3.9	0.6	
			2620	2000a	BOD	2.4	0.45	

a = acclimatized; m = municipal.

Table 65 - Oxygen Consumption of "Dairy Wastes" k $Days^{-1}$ in Laboratory Aerators or Activated Sludge Plants

Waste	Treatment System	Temp., °C	Waste Conc., ppm	Sludge Conc., ppm	Basis	k_i Purif. $Days^{-1}$	k_2 Oxidation $Days^{-1}$	Reference
Skim milk	20 L aerator F+D	30	1000 solids	1000a	COD	7.2-19.0-30	.9-1.4-5.7	473
			1000	2000a	COD	10.5	.9	
Skim milk	20 L aerator F+D	30	1000 solids	500	COD		1.9-3.8	476M[1]
Skim milk	20 L aerator F+D	30	1000 solids	500	COD		.3	475M
				500	COD		.19	
			1000 solids	500	COD		1.5 1st k	SR[2]
							.13 2nd k	
			0	500	COD		.2	M, SR
Skim milk	lab aerator F+D	2	1000	1125	COD	7	.3	834M
		10	1000	1125	COD	12	.47	834M
		20	1000	1125	COD	10	.36	834M
							.16	834M
		30	1000	1125	COD	5		834M
Skim milk	-	-	-	-	BOD	-	.02	408a
Sweet whey	20 L aerator F+D	30	1000	1000a	COD	19	1.7	473
Sweet whey	12 L aerator F+D	30	0	2000s	COD		.26	516M
				2000a	COD		.13	516M
Sweet whey+NH_4OH	12 L aerator F+D	30	0	2000s	COD		.58	516M
				2000a	COD		.4	516M
Lactose (in skim milk)	20 L aerator	30	500 solids	1000	COD	48		473
Cheese plant waste	2 stage mixed		1500w		BOD_5		1.3	561

Notes: F+D=fill & draw
a=acclimatized; m=municipal; s=skim milk
[1] M=estimated moments
[2] SR=estimated successive results
[3] ML=Moore Lag method

components have been treated as "oxidation", k'_2 in Tables 64 and 65.

The data in these tables should be used with caution because, for the most part, they are limited to skim milk and sweet whey rather than milk plant wastes. Further, the kinetic data from some references (374, 475, 476, 516, and 961) were calculated by the methods indicated from data presented graphically. The high variability of the data is present in studies such as that for skim milk (473), as well as the data extracted from curves in the literature.

Loading and Sludge Dependence: The work of Gellman and Heukelekian (392) indicates that both the purification and the oxidation reaction for skim milk are dependent upon the sludge concentration at a fixed BOD load, L, and upon the BOD load at a fixed sludge concentration, X. In general, the rate constants increase linearly with the sludge concentration and decrease linearly with waste load.

The relationship between rate constant, k_i, and X and 1/L can be explained by reactions for purification which are the form of equation [12]

$$\frac{dL}{dt} = \left[\frac{K_i X}{K_s + L}\right] L \equiv 2.3\, k_i L \qquad [12]$$

when L is greater than K_s. Under these conditions the apparent rate constant, k_i, for the purification or oxidation time periods would be proportional to the sludge concentration, X, and nearly inversely proportional to BOD or COD concentration, L.

Values of K_s for various substrates, including skim milk and lactose, are shown in Table 66.

Table 66. Values of K_s for Various Substrates (after 314)

Substrate	K_s, mg/ℓ
Skim milk	100 (BOD) (408)
Lactose	20
Glycerol	12
Glucose	4

K_s may be interpreted as the substrate concentration, L, at which the BOD removal rate is one-half of the maximum removal rate, K.

The waste composition data presented earlier in this report, indicate that dairy waste loads, L_o, often will be 10 times greater than K_s, i. e., greater than 1000 for the skim milk fraction, greater than

200 for the lactose fraction and perhaps greater than 120 for the lipid fraction.

According to equation [12]and the cited value of K_s, data for skim milk in shaker flasks with municipal or acclimated study (392) should show rate constants that double when sludge concentration, X_a, is doubled and halve when waste concentration, L, is doubled for loading greater than 1000 ppm. However, they do not! In fact, this doubling of rate constant k_i, with doubling sludge concentration, X_a, is true only when the sludge concentration is 2000 ppm or more.

If equation [12] does fit the disappearance of waste, L, over the range of loading and biomass concentrations from simulated plants to the BOD bottles, it would appear that K_s for skim milk may be greater than 100. Such values of K_s are substantially above those values encountered in most sewage or industrial wastes (312a).

For skim milk concentrations as large as 2000 ppm, the BOD removal rate would likely be more nearly zero-order than first-order: for $L > 10\ K_s$ equation [12] becomes

$$\frac{dL}{dt} = K_i X \qquad [13]$$

At these high BOD loads the BOD removal rate is proportional only to the biomass concentration, X.

For skim milk concentrations between 2000 and 20 ppm, i. e., $10\ K_s > L > 0.1\ K_s$, the forced first-order approximation of equation [12] should be a fairly good first approximation for specified biomass and waste concentrations, X and L. In some instances (473), the investigators have noted the approximate nature of the first-order approximation.

In other cases the X or L changes were small during the initial, short, "purification" period or the much later "oxidation" period (perhaps less than 30 to 40 percent over the test period). For such small changes the inadequacies of the first-order curve fitting approach could be masked by the variability in the oxygen demand.

When most of the waste concentration, L, has been removed so that the waste load is less than one-tenth of the K_s-value, equation [12] for waste removal becomes

$$\frac{dL}{dt} = \left[\frac{K_i}{K_s}\right] X_a L \equiv 2.3\ k_i L \qquad [14a]$$

For these low waste concentrations of $L \leq 10$ mg/ℓ for skim milk BOD, the removal rate, dL/dt, is proportional to both the biomass concentration, X, and the waste concentration, L. Also, the apparent first-order rate constant, k_i, is proportional to the average biomass concentration, X_a. Thus

$$\frac{L}{L_o} = 10^{-(K_i/2.3\ K_s)X_a t} \qquad [14b]$$

This falling rate behavior is evident in the BOD bottle data for mono- and disaccharides, (after an initial lag period, (1179)) and for the milk fractions. This equation is also a good approximation for the BOD-bottle studies of Hoover et al. (475), although the data could be better fitted by a linear and two concurrent first-order components. All of these studies were conducted at low waste concentration, L, and low average biomass concentration, X_a.

The relationship expressed in equation [14a] appears similar to that of equation [15a] used by Eckenfelder (312a) and others for most substrate mixtures with low initial BOD values of ≤ 500 mg/ℓ. This equation

$$\frac{L}{L_o} = \frac{1}{1 + K_a X_a t} \qquad [15a]$$

can be written as

$$\frac{L_o - L}{t} = K_a L X_a \qquad [15b]$$

which is the finite-difference form for the Michaelis-Menton style, equation [12], for low level waste removal, equation [14b]. However, this equation is derived by describing the waste removal rate as

$$\frac{dL}{dt} = \frac{K_a X L^2}{a} = \left[\frac{K_a L X}{a}\right] L \cong 2.3\ k_i L \qquad [16]$$

for nearly constant initial waste concentration. (Eckenfelder (312a) uses the symbol a to represent the yield of new cell mass per unit of BOD or COD removed.)

If this more familiar relationship were to describe the experimental data, the k_i values should double with either doubling biomass concentration X or with doubling waste concentration, L. The limited data in Table 65 indicate that the rate "constant" rarely increased with double waste concentration, but rather k_i generally decreased.

Thus, it appears the Michaelis-Menton form of kinetic description, equation [12], can be better forced to fit the range of waste and biomass concentrations for skim milk wastes than equation [16].

Differences Among Treatment Systems

The data in Table 64 are for milk or milk fractions in BOD bottles or shaker flasks. The data in Table 65 are for laboratory aerators or activated sludge plants.

Generally the rate constants for the laboratory aerators or activated sludge plants are higher than those found in shaker flasks or BOD bottles. The USDA group suggested that the agitation-aeration method may have been responsible for the lower rate in the shaker-flasks and BOD bottles.

Harding (429) pointed out that the oxygen supplied in the laboratory aeration studies of Hoover, Porges and associates which make up the bulk of the data in Table 65 were about 30 times what is actually provided in milk waste aeration treatment plants. This may or may not have any influence on the rate of oxygen uptake. However, as discussed earlier, data of this group indicate that at dissolved oxygen contents of about three to one-half parts per million there was a small fractional-order dependence of oxygen uptake upon oxygen concentration.

Composition Influences: The composition of the dairy waste appears to influence the treatment rates.

First, in Table 64 we note that the rate of oxidation for milk components are less than that of whole milk itself. This is in agreement with lower BOD_5/COD ratios of milk fractions as reported earlier in this study.

Second, the rate of oxidation of α-lactose and galactose are substantially lower than that of other simple sugars, and, due to a dependence upon β-galactosidase activity, the oxidation of both α- and β-lactose proceeds after a lag period of one and two days, respectively.

Further, the rate of oxidation of skim milk waste in a purification plant is on the order of five times larger for the influent as compared to the effluent. This also corresponds to reduced BOD_5/COD ratios reported for treated vs. untreated dairy waste as presented earlier in this report.

The oxygen depletion rate during the transfer of lactose (with NH_4, nitrogen) to the biomass appears to be several times larger than the depletion rate for skim milk. The purification and oxidation rates (473) for whey (i. e., lactose, and serum protein nitrogen) are also higher, almost double, than for most skim milk data (473).

Earlier discussion indicated that nitrogen metabolism, especially organic nitrogen metabolism, is much slower than even lactose cleavage and metabolism, and might lead to a BOD/N availability imbalance. Such an imbalance would be expected to be more severe for those wastes with added whey. Such substrate changes could induce microflora enzyme systems, and/or their metabolic intermediates which were somewhat different for skim milk or lactose as compared to domestic sewage. The poor settling of acclimatized sludge with accidentally-added whey and still poorer settling of whey acclimatized sludge (473) may be a consequence.

Temperature Effects: The evidence concerning the influence of temperature upon the effectiveness of activated sludge treatment appears to be conflicting.

The kinetic data (834) in Table 64 indicate that the most rapid rate of purification appears to occur in the vicinity of 10°C. At higher and lower temperatures the purification rate is decreased. No evidence is available as to the oxidation rate for the same system. Kinetic analysis also showed that the fraction of BOD to COD in the waste increased as the temperature increased from 2 to 30 degrees. Perhaps it was the somewhat faster COD removal, but more likely the greater oxygen utilization evident in their graphs, which led Porges and co-workers to suggest 85-90°F, approximately 30°C, as ideal temperature for activated sludge treatment of dairy wastes. Further, it was their experience that this temperature was approximately that encountered in the effluent to the dairy treatment plant and, when the temperature dropped lower than about 70° they suggested the use of steam to heat the waste to the ideal region (834b).

Industrially, the temperature appears to be quite important. Trebler and Harding (1138) maintain that the optimum is about 86°F. At this temperature the rate of endogeneous respiration is reported to be approximately one-tenth of the aerobic "fermentation" rate. At 68°F the fermentation rate appears to be about 38% of that at 86°F and the endogeneous respiration is practically stopped. At 50°F the rate of fermentation is "stopped for all practical purposes in commercial waste disposal plants," although in laboratory experiments (834) it is said to be occurring at about 37% of that at 86°F.

Contrary evidence is fragmentary. One dairy treatment plant in the field survey reported no apparent improvement in performance when dairy waste at about 20-25°C was heated to 30°C. This facility has irregular, unexplained periods of poor performance.

Svoboda and co-workers (1085) have reported that ambient temperatures as low as -10°C did not adversely affect treatment efficiencies (1085). The temperature in the aeration basins were not reported. Even with fluid temperatures of 2°C laboratory data (834) indicate significant biological activity. It is possible that the psychrotropic microorganisms which are normally discharged from a waste treatment plant to a sewer treatment plant have gained dominance over the normal flora, particularly if the aeration weight was high.

Wuhrmann (1278a) has provided evidence that "the metabolic rates cannot be affected by temperature in a situation where the amount of nutrients applied to the system is more effective as a limiting parameter than temperature." The data from a lab-scale treatment system using domestic sewage as a substrate indicates:

1. Higher organic removal at temperatures above 13°C than at temperatures below 11°C at all hydraulic loads, O_2 concentrations and MLSS concentrations.

2. Higher organic N and BOD removal at the lower temperatures only at low hydraulic loads ($9m^3/m^3$day) and low O_2 concentrations (1 ppm) and low MLSS (600 ppm) and lower removals for the converse conditions.

3. Greater endogenous respiration at 25°C for sludges grown at the lower temperatures, and in both instances dramatic increases with increasing sludge loads up to BOD_5/MLSS ratios of 1.5.

Eckenfelder (312a) has reported the influence of temperature upon the rate constants for activated sludge, aerated lagoons and the processes such as gas transfer, nitrification, oxygen utilization and oxygen solubility which occur within the systems. These data are summarized in Table 67.

For the convenience of those readers from the food industry the temperature sensitivity has been reported in terms of z value, where the z value is the number of degrees Fahrenheit required for a ten-fold change in the reaction rate.

Still other readers may be more familiar with the Q_{10} expression, which is the ratio of the reaction rate at 10°C above the reference temperature to that of the reference temperature. From elementary chemistry the van't Hoff relationship suggests a Q_{10} of 2 for chemical processes. The z value corresponding to this Q_{10} of 2 is 60.

The data in Table 67 indicate that the rate of oxygen transfer would be expected to decrease with increasing temperature and the increased oxygen solubility found at low temperatures would give θ value of 0.995 to 0.996 and slightly higher levels of O_2 supplied at reduced temperatures. Eckenfelder (312a) has suggested that the dramatically lower O_2 utilization rate at lower temperatures would permit a greater fraction of the internal portion of the floc to be in an aerobic condition. As a result, the activated process is relatively insensitive to temperature. This floc diffusion-utilization effect would be heightened by the slight sensitivity to oxygen level reported for the data of

Table 67 - Temperature Effects on Waste Treatment Processes

Process	θ	z(°F)
Activated sludge	1.0* to 1.03	- to 43.5
Trickling filter, & aerated lagoons	1.035 1.06 - 1.08	37.3 22 to 16.6
Oxygen transfer, K_L	1.028	46
Bubbles, K_La	1.02	64.6
Nitrification	1.143	9.6
Oxygen utilization	1.074 - 1.085	18 - 15.7
Oxygen solubility	0.977	-55

*Low loading to high loading levels

$k_2/k_1 = \theta^{(T_2-T_1)} = 10^{(T_2-T_1)/1.8z}$

Hoover and Porges (469). The net effect might be that a lowly loaded system at oxygen levels in the neighborhood of 1/2 to 1 ppm might perform in a somewhat superior manner at reduced temperatures. Thus, Svoboda's finding is to be expected under somewhat special low loadings. A conventional activated sludge system on intermittent loading due to one shift of plant operation per day might be so loaded.

The plant which used heated waste unsuccessfully, intermittently experienced stable foam in a contact stabilization system with 300+ pound BOD/1000 ft^3 day load in the contact tank and a BOD/solids loading of about 0.5. If under these conditions gas transfer became limiting, temperature increases might not help.

Sludge Yield: Sludge yields for various substrates are reported in Table 68.

The limited data for skim milk solids, artificial dairy wastes and fortified sewage-whey mixtures indicate that the expected sludge yields are of the same order as those encountered for domestic sewage and many industrial wastes. These waste yields are also of the same order of magnitude as those of the sugars and amino acids and organic acids which make up the wastes.

Table 68 - Conversion of Organic Materials During Biological Treatment

Substance	Organisms	Per Cent Conversion to New Growth, 100a	Reference
Carbohydrate	Act. sludge	65-85	820
Alcohols	Act. sludge	52-66, 9-31	820, 391
Amino acids	Act. sludge	32-68	820
Organic acids	Act. sludge	10-60	820
Maltose	Act. sludge	53	820
Glucose	Yeast	49-59	152a
Glucose	Act. sludge	44-64	923a
Sucrose	Act. sludge	58-68, 68	923a,820
Lactose	Act. sludge	114	820, 820a
	Act. sludge	52	Calculated in - 469
Casein	Act. sludge	47	Calculated in - 469
	Act. sludge	50	Calculated in - 469
Skim milk solids	Act. sludge	50-52, 55	469, 476
	Act. sludge	36*	Calculated in - 594
	Act. sludge	58*	Calculated in - 594
	-	48	408a
Art. dairy waste	Arthrobacter	44-48**	3
	Achromobacter	36-40**	3
	Pseudomonas	40-42**	3
Milk waste water	Act. sludge	49***	182
Sewage, whey, NH_4	Act. sludge	40	857a
W/O NH_4	Act. sludge	71	857a
Brewery	Act. sludge	93	312a
Domestic sewage	Act. sludge	49-64	312a

* COD basis
** BOD_u direct basis
*** Net conversion

Adamse's work with different microbial species on the treatment of artificial dairy waste (3) indicates that the prominent microflora will significantly influence the yield from a dairy substrate.

There is some evidence which indicates that lactrose without ammonium nitrogen fortification, whether present as the primary substrate or in a municipal system with domestic sewage with some other industrial wastes, produce significantly higher sludge yields (857a, 820, 820a), and, with NH_4 may produce a poorly settling floc (516, 831). Other data for various carbohydrates and simple sugars systems indicate that these substrates generally produce high yields.

The yield should be expected to vary with the available C:N ratio. Symons and McKinney (1102), working with sodium acetate and other substrates have found the sludge composition to be $C_{1.0}H_{1.7}O_{0.6}N_n$, with the value of n being dependent upon the available C:N ratio. The excess material above a base empirical formula of $C_5H_8O_2N_2$ appears to be stored materials.

Dairy wastes appear to have similar empirical sludge compositions such as $C_5H_7NO_2$ as reported by Hoover and Porges for a laboratory skim milk system (469) and by Kountz and Forney (594). Because of the reported storage of carbohydrate (834, 594, 6) the actual nitrogen content may be as low as 7.5-8.4% rather than the 12.4% required by the empirical molecular formula.

The calculations of Porges et al. (834) (see Fig. 40) suggest an increase in $COD_{new\ cells}/COD_{available}$, and $COD_{new\ cells}/COD_{removed}$, as well as increased COD removed as the temperature is increased from 2° to 30°C. The estimated maximum $COD_{stored}/COD_{new\ cells}$ are 2.9, 3.9, 6.3 and 5.5 at 2°, 10°, 20° and 30°C, respectively. At the lower temperatures the estimated stored COD disappears slowly, if at all. In these calculations the fraction of O_2 used, which was converted into new cells, was presumed constant.

Wurhrmann (1278b) reported an increase in the yield (of organic carbon) from substrate removed (C) for sewage treatment basins operating at 11°C or less as compared to those operating at 13°C or greater. Yield, $\hat{Y}_G$, is defined as

$$(X_{out} - X_{in}) = \hat{Y}_G(S_{in} - S_{out}) \qquad [17]$$

where

$X_o - X_{in}$ = increase in sludge concentration when all solids are suspended in the effluent

$S_{in} - S_{out}$ = decrease in concentration of limiting substrate from aeration basin inlet to outlet.

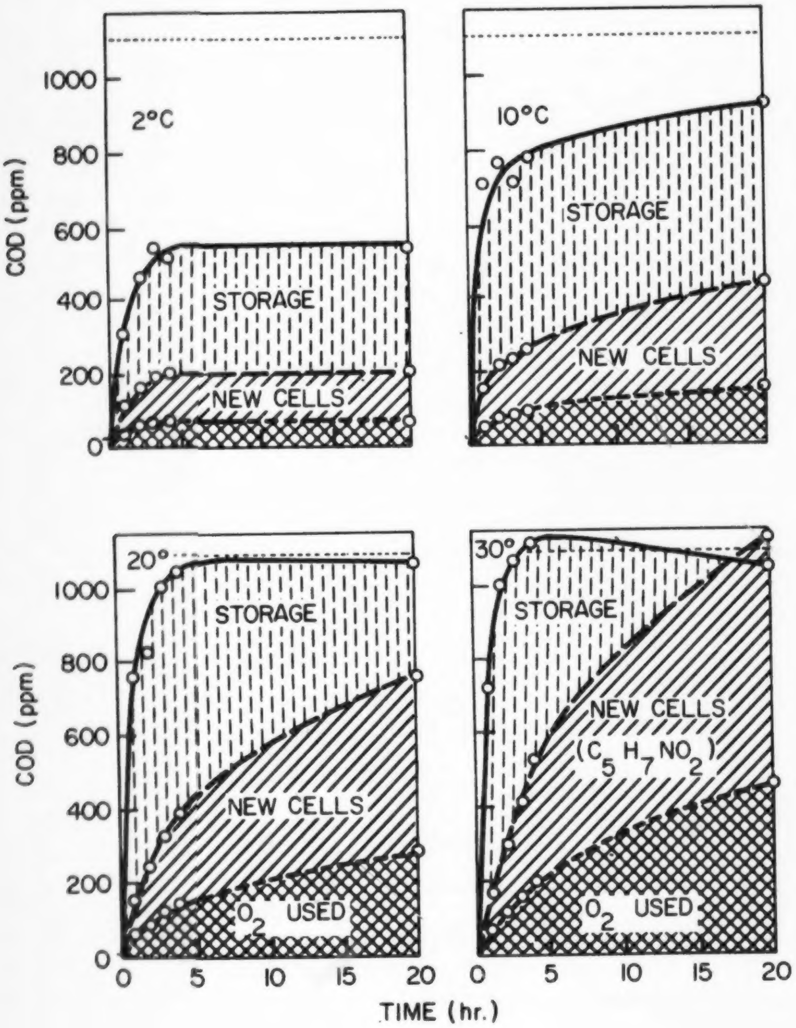


Figure 40 - Purification, oxidation, storage and synthesis for 1000 ppm sludge and 1125 ppm skim milk COD (after Porges et al. (834). COD used for energy and cells estimated from mass balance; i.e., COD 2.67

Wurhrmann attributed these results to the effect of temperature on other factors which contribute to oberall sludge increase. In fact, where corrections are made for influent suspended solids removal, S^*_{in}-S^*_{out}, inert materials in the influent, I, and sludge catabolism, bx_{av}, the sludge increase is seen to be

$$X_o - X_{in} = Y_1(S_{in}-S_{out}) - Y_2(S^*_{in}-S^*_{out}) + I - bx_{av} \qquad [18]$$

When Wurhrmann (1278) made estimated corrections for these additional factors he found the true yield, Y, or a, was not significantly influenced by hydraulic loading, or sludge concentration. There was a non-significant trend toward increased yield, Y, at reduced O_2 levels.

Sludge Catabolism: In the early studies with skim milk systems, a substantial portion, i.e., 92% of the organic portion of the biomass formed by transfer of waste appeared to biodegradable (469, 466, 833).

Subsequent studies with dairy (594) and other wastes (861, 1102, 1215) have shown that operation without sludge removal is not feasible because of buildup of poorly degradable materials, such as polysaccharides formed as a metabolic storage product during a shock load (574), or carbohydrates, proteins or lipids from seemingly normal metaolism, (1215), 232-233, 5, 201). Although plants of this period were reported to operate without sludge removal, it appears that most of these systems may have lost solids in the form of floating sludge-effluent complex or pin point floc (1138). There is some later evidence with dairy waste that perhaps 20-25% of this biomass is not biodegradable (594, 834). Porges and Jasewicz (831) found an accumulation for whey wastes, while Kountz and Forney (594) have reported the accumulation of nonoxidizable sludge was at a rate of 0.7% per day.

This non-biodegradable fraction is larger than the 10-15% found by Washington and Symons (1215) for a loading of 40 pounds of sodium acetate COD per day/1000 cubic feet. (Other substrates used were flucose and glycine.) A major portion of their inert volatile solids appeared to be polysaccharide in nature with significant fractions of fatty acids and organic nitrogen.

The fraction of the biomass degraded per day, b' or nb, for various systems, is reported in Table 69.

It appears that the highest rate of degradation is achieved at temperatures of about 90°F with a sludge equilibrium at about 2.5 to perhaps 3 times the BOD loading. As the temperature is reduced, the degradation rate appears to decrease from 20-23% to 16% and later to 10% at 70°F. The data suggest a θ value for endogenous respiration of 1.064-1.078.

Table 69 - Sludge Endogenous Respiration

Waste	Percent Loss/Day	Equilibrium Vol. SS/BOD Feed	Remarks	Reference
Skim milk	2.3	12-15	Pilot plant continuous	595
Skim milk	30 [sic]	-	77°F, pilot plant batch	834b, 314
Dairy waste	12-24	-	Pilot plant	466
Dairy waste	20-23	2.5	90°F, pilot plant batch	586, 589, 827, 830a
Dairy waste	10	5.0	70°F, pilot plant batch	590, 827
Dairy waste	5	-	Industrial "experience"	432
Dairy waste	16	3	Preliminary pilot plant (batch)	591
Whey	5.2-6.3	10	Projection from lab-scale study	831
Domestic, whey w NH_4	5.5			857a
w/o NH_4	6.5			857a
Domestic sewage	14.2	-	77-86°F	312a

Composition appears to have a significant effect on the rate of endogenous respiration. Only with skim milk wastes in the laboratory are endogenous respiration rates as high as 10 to 30%.

When the waste is no longer exclusively or predominantly skim milk, lower values of oxidation rate in the vicinity of 5-7% per day are reported. The oxidation rates reported in Table 64 for renneted milk, whey (sweet), and acid milk, glucose, α-lactose, and effluent from skim milk treatment are also from 0.03 to 0.07 times 2.3 or 8, 50, and 16.1 percent per day.

It is not immediately evident why the study of Kountz and Forney (594) yielded an apparent endogenous loss of as low as 2.3% per day for a skim milk substrate. There are several possibilities, however. First, the sludge load, pound BOD/pound X, day was about 0.06. For the other laboratory studies the sludge load was about 0.9 to 2 pound BOD/pound X, day. The USDA pilot plant data for fill and draw systems have to design loadings of about 0.4 and 0.8 pound BOD/pound X-day for fill and draw and continuous systems (827, 834a). At these loadings Wurhrmann (1278b) reports endogenous respiration rates for sewage which are 4.6-10.7 and six to twelve times that at a sludge loading 0.06 pound BOD/pound X, day. Similar quanitative relationships for dairy wastes could explain the nearly ten-fold difference in sludge oxidation rates.

Second, the sludge age, $G = X_{av}/\Delta X$ was large, perhaps on the order of 250. Wurhrmann (1278b) and others (see 1278a) reported corresponding reductions with increased sludge age for sewage. As a first approximation, the relationship was $G = 10 \exp(Q_{O_2}-13)$, where Q_{O_2} is the endogenous respiration rate, mg O_2/g X-hour.

Oxygen Demand: The oxygen requirements of an activated sludge system can be related to the equation for the oxidation kinetics of the system. This can be done by substitution of the expression for waste "utilization" in equation [10] below.

$$C = (1-nY)\,(dF/dt) + nbX \qquad [10]$$

The expression for rate of waste utilization, $dF/dt \equiv dL/dt$, may be either the first approximation as in the equation [12b] or in the Michaelis-Menton form as in equation [12a].

$$\frac{dL}{dt} = 2.3k_1L \qquad [12b]$$

$$\frac{dL}{dt} = \left[\frac{K_m - X}{K_s - X}\right]L \qquad [12a]$$

Rich (877a) and Eckenfelder (312a) in their texts use a slightly different terminology than that expressed in equation [12a] above. In Rich this relationship is expressed in terms of concentrations rather than masses, VpC:

$$\frac{\Delta C_{O_2}}{\Delta t} = a'\frac{\Delta C_L}{\Delta t} + b' \qquad [19]$$

In Eckenfelder the relationship is expressed as

$$\frac{\text{lb } O_2}{\text{day}} = a' \frac{(\text{lb BOD}_5\text{, removed}) + b' (\text{lb MLSS})}{\text{day}} \qquad [20]$$

Comparison of these alternate expressions indicates that first, the coefficient, a' is (1-nY) where Y or a is the sludge yield tabulated earlier (Table 67) and second, the fraction of waste oxidized per day

$$nbX = b' = b'X \qquad [21]$$

and nbX = 2.3 $k_{\text{endogenous ox.}}L$ of Tables 64 and 65.

McCarty (607b) reports that the value of n is generally close to 1.4. This is somewhat higher than the empirical requirement of 1.25 gram of O_2 per gram of dry weight reported by Hoover et al. (476) but of the same order as the 1.44 pound O_2/pound ash-free sludge oxidized used by this group as a design value in USDA Handbook #176 (834b).

When the yield values, Y or a, are about 0.5 as reported for skim milk, and n = 1.4 then a' values are expected to be about 0.3, and when n = 1.25, are expected to be 0.38.

If yield values were as high as 0.72, as for lactose in Table 68 and n were still 1.4 then a'-values would be negative. This suggests that Y and n both will vary with the initial amount and degree of conversion of stored materials and the build-up of metabolites. The current state of the art does not permit prediction of this behavior. Thus the design engineer must turn to experimental confirmation of a' (and probably b', as well as a and b values).

Some experimental values for the yield coefficients a and a' and the rate constants b and b' are summarized in Table 70. All are for laboratory systems. All but the USDA study (469) appear to have been for BOD/MLSS loadings of about 0.06 to 0.7 with more work being done near the lower loading. The data of Quirk et al. (857a) are for a waste composed of 1.55% whey, 0.09% skim milk, and 15.90% settled domestic sewage with the remainder being city water.

As indicated before, Y or a would be expected to increase with increasing whey content, if storage were included, and n would be expected to decrease correspondingly. The n-value appears to be on the order of 0.7 to 1.0 for domestic sewage-whey without nitrogen, 1.2 for early skim milk studies, and 1.44 for the bulk of the USDA group effort. The b and b' values are probably quite sensitive to loading and temperature as discussed above. By coincidence, the BOD/gram cell ratio is 1.44 and the mg O_2/mℓ conversion factor is 1.43, so that a Q_{O_2} of 10 mℓ O_2/g sludge-hour corresponds to a b_2 value of about 1%/hour.

Table 70 - Yield and Demand Parameter for a Synthetic Waste

Waste	Basis for a, a'	a	a'	b	b'	Ref.
Skim milk	Organic BOD	0.52[1] 0.60[2]	0.375 0.43[2]	0.24 - 0.05[3]	0.345 - 0.07[3]	(469, 827, 834b)[3]
Skim milk	BOD	0.48	0.40	0.045	0.065	408a
Skim milk	BOD	0.36[1] -0.58	0.18	0.02	0.046[4]	594
Domestic whey						
w NH_4	BOD	0.40	0.35	0.055	0.075	(857a)
w/o NH_4	BOD	0.71	0.48	0.065	0.065	(857a)

Notes:

[1] For assimilation period

[2] Using empirical BOD/°C ratio of 0.8 (466), COD/mass ratio of 1.08 (1.12 for lactose, 1.42 for protein, 1.08 overall)(468)

[3] Industrial values

[4] Using empirical factor of 1.44 pound O_2/pound sludge

Trebler and Harding (1138) have pointed out that the storage of COD, (as reported by Porges et al. (834), (See Fig. 40) and Kountz and Forney (594)) reduces the effective value of both a and a' during the three-hour "assimilation" period. For example, the a is 0.23 rather than 0.67 and a' is 0.14 rather than 0.4 for the COD estimates of Porges et al. (834) at 30°C.

Oxygen Transfer Characteristics: The oxygen required by the biomass must be transferred from the air at a rate which will maintain the desired oxygen concentration C_{O_2} in the vicinity of the cells. Evidence from other waste systems indicates that the characteristics of dairy wastes may significantly affect the transfer of oxygen. Poorer transfer characteristics become of concern because relatively high oxygen requirements for the contact period of the activated sludge process, particulrly for the lactose portion, are higher than in municipal systems.

Often the resistance to gas transfer is concentrated at the liquid side of the liquid surface or gas bubble. For such a system, the rate of oxygen transfer may be approximated by the expression

$$\frac{dC}{dt} = K_L a(C_s - C) \qquad [22]$$

where

C = dissolved oxygen concentration
C_s = dissolved oxygen concentration at saturation
a = interfacial area per unit volume
K_L = liquid transfer coefficient

The waste characteristics may affect this transfer expression by influencing the dissolved oxygen concentration at the gas-liquid surface, C_s; the surface area of bubbles or waves, **a'**, and/or the transfer rate, k, or thickness of the liquid film, δ, that is $K_L = k/2\delta$.

The ionic constituents very likely reduce the solubility of oxygen in the waste, C_s, 5 to 15% as it does in sewage or paper manufacturing waste treatment systems. (Table 70)

The waste discharged from the plant could swing from a pH of 4.4, for inadvertent whey discharge or a pH of 6.2 for whey wash water to a pH of 10 during normal cleaning or a pH of 13 during cleaning of evaporators or ultra-high temperature processing units. Chloride ion is present at concentrations from about 20 to 250 ppm from normal cleaning and sanitizers and could be present at concentrations as high as 26,000 ppm for discharge of brines from cheese manufacture. There are other ions present, approximately 35 ppm phosphate and 150 ppm potassium. Our best guess is that the effective ionic strength may range from 0.01 to 0.2 for the waste discharged to the sewer. This concentration could reduce the oxygen solubility as much as 15% as well as influencing the kinetics of biological treatment. Actual experimental data on solubility of oxygen in dairy waste systems are not available.

Eckenfelder (312a) has used two efficiency parameters alpha, α, and beta, α' to characterize oxygen transfer efficiencies.

$$\text{Alpha } (\alpha) = \frac{K_La \text{ of the waste}}{K_La \text{ of pure tap water}} \qquad [23]$$

$$\text{Alpha } (\alpha') = \frac{K_L \text{ of the waste}}{K_L \text{ of pure tap water}} \qquad [24]$$

The first ratio represents a ratio of the relative transfer rates (for a constant driving force $C_s - C$). The second ratio does not include interfacial area, a, and considers only the transfer coefficients K_L.

Table 71 shows that substantial reductions in transfer rates, α, are encountered in sewage and industrial wastes or fermentations. The surface active agents such as antifoams, and detergents are one of the major culprits. In dairy wastes concentrations of surfactants as high as 20 to 200 ppm, based on a mass balance, are to be expected. These are introduced as ingredients in the cleaning solutions. But the milk proteins themselves possess surfactant properties and, like peptone broths, would be expected to significantly lower the transfer ratio, α.

Significantly reduced transfer ratios, α, are also reported for filamentous systems such as in industrial fermentations with molds, and might be expected in other filamentous systems as well. In many organisms, expected in dairy waste treatment systems, such morphology may be induced by oxygen availability or by substrate, as previously discussed.

Surfactant materials may significantly decrease the transfer rates at relatively low concentrations. Figure 41 from Eckenfelder (312a, 314a) shows the influence of one detergent material on the ratios α and α' upon the mean diameter of the gas bubbles, D_B.

Aiba, et al. (9a) compared the findings of several investigators (9b, 213a, 314a, 654b, 687a, 1121a) with respect to the effect of detergents on gas transfer constant, K_L. These investigators found concentration dependence like that shown in Figure 41 with α values on the order of 0.20 to 0.40. This minimum gas transfer coefficient α occurred at surfactant concentrations on the order of 10-50 parts per million which are in the range reported for dairy waste waters. The minimum surface tension was generally at substantially higher concentrations ranging from 100 to 1000 ppm.

Table 71 - Influence of Waste Characteristics on Gas Transfer

Waste	$C_{s\ waste}/C_{s\ water}$	$K_La_{waste}/K_La_{water}$	Remarks	Ref.
Sewage	0.95			
aerated		0.72 to 0.90	0 to 4 hrs.	315
fresh		0.26 to 0.46		562
septic		0.16 to 0.19		562
Paper Mfg.	0.85 - 0.95	0.45 to 0.79	0 to 4 hrs. aeration	315
Peptone				
25 ppm		0.5		315
1000 ppm		0.2 to 0.4		315
Anionic Detergents		0.35 to 1.0	50 ppm various	627a
Mold suspension		0.2	10,000 ppm	382a
with antifoam		0.1	10,000 ppm antifoam	382a

It appears that the transfer coefficient ratio, α, will be quickly reduced to a minimum value and bcome nearly constant above a critical micelle concentration. The overall transfer ratio, α', will decrease more slowly with increased concentration and will achieve a minimum value at a larger value of waste or surfactant concentration. At higher surfactant concentration (314b) the increase in interfacial area due to smaller bubble size may overcome the decrease in transfer coefficient, K_L.

These findings are for diffused air systems at low-to-intermediate mixing or turbulence in the waste. When the turbulence is quite intense, or the aeration is achieved by surface aeration devices, the tendency of surfactants to increase the air-liquid surface will be expected to predominate and α to increase with increasing surfactant concentration.

These surface-active agents tend to concentrate at interfaces such as the air-waste interface, and to saturate the surface if the rate molecular and eddy diffusion of surfactants to the interfaces exceeds the rate of new surface formation.

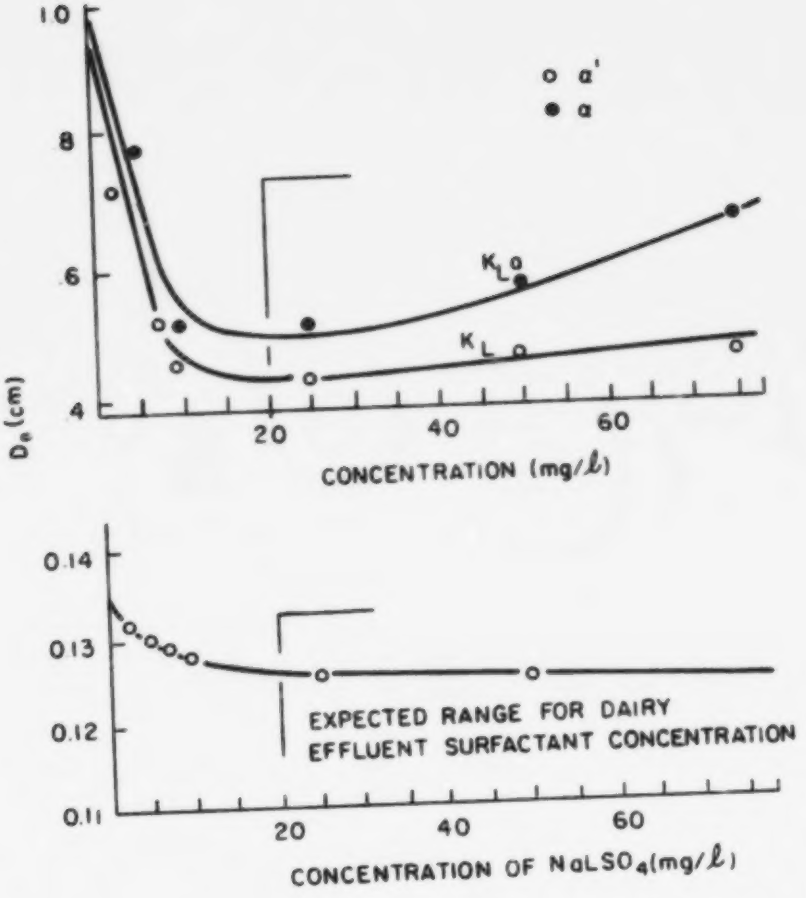


Figure 41 - Oxygen-transfer characteristics in dilute solutions of sodium lauryl sulfate (after Echenfelder (312a, 314a))

Mancy and Barlage (654a) maintain that there are two possible modes of interference with gas transfer. The first is said to be caused by the reduced interfacial area available for gas transfer blockage of dissolution sites at the interface or distortion of intermolecular forces between the gas and liquid molecules. The second influence they suggest is that of increased water surface viscosity, supression of hydrodynamic activity at this interface, or the formation of viscous subsurface hydration layer.

The surface active agents should also be expected to collect at the cell wall, and to be a significant factor in the formation of micelles as they do in biological systems. If the storage in the biomass is in part carbohydrate material with properties like sea weed polysaccharides, cell clumping leading to dense flocs or stable foams are entirely possible. (Some of the surface-active serum proteins interact with these sea weed polysaccharides to form tough, stable foams as reported earlier).

When these interactions are occurring, the major resistance to gas transfer may not be the liquid interphase at the bubbles but the transfer resistance in the interspace of the biological floc. When foams occur many operators are forced to cut back on the air flow rate, resulting in a further decrease in available O_2 and metabolic activity. This course of action may lead to a further microflora shift and/or to further carbohydrate storage.

Hlavaka, (460) made an investigation of the effect of ABS type detergents on the treatment of a dairy waste in both laboratory and semicommercial operations. In the laboratory, he reported that a concentration of 20 mg/l had no significant effect on efficiency. When the ABS concentration was raised to as high as 60 ppm, foaming increased and sedimentation was impaired but the purifying effect remained at a high level provided that intensive aeration was maintained. In a semicommercial operation, however, the air supply was limited to 326 ft^3/pound-5-day BOD. When the ASB concentration was approximately 60 ppm the result was a significantly poorer purifying effect.

Aeration Methods: An examination of the reviews by Trebler and Harding (1139), Hauer (441), Fisher (363), and Trebler and Harding (1138) and the literature cited indicates that most of the methods which have been devised for the aeration of activated sludge systems have been applied at one time to dairy wastes.

These methods include drilled pipe diffusers (440, 441, 438, 590, 331, 336, 752, 711) - other diffusers (103, 1139, 1110, 1109, 1165a, 439, 930, 590, 1109, 1128, 429), spinning discs (441), hollow shaft diffusers (441, 962, 964, 590, 439, 1141, 1139) Kessener or Kafig brushes (208, 102), and TNO cage rotors (789, 790, 791), jets (440, 586, 590, 1138, 834b, 438, 1228, 1139, 479) and floating aerators (542, 1050).

Industrial experience indicates that aeration devices with relatively large openings such as large nozzles or wide spaces, as in brushes, perform most satisfactorally. Some blockage is undoubtedly due to grit, casein particles, or "milk stone" buildup, but much of the blockage appears due to gummy materials. These gums seem to be associated with lactose and galactose metabolism, since they appear to be more prevalent than in domestic wastes. All devices appear to require periodic checking. Further, a screen appears necessary on the inlet of diffusers and jets.

In 1955, during the peak of dairy waste treatment studies in the U. S., Trebler and Harding (1139) reported on the state of the art of aeration of dairy waste.

Plates or tube-type diffusers were reported to provide economical service on a power requirement basis but required frequent, costly cleaning (1139). Plastic-wound diffusers were tried in several plants, generally unsuccessfully. In one instance steam was introduced into the air headers with a doubling of the operating time before cleaning was required. But in other plants this technique had proved ineffective.

Many small plants then moved to the use of drilled-pipe headers (1139). The optimum hole diameter appeared to be about 3/16-inch (or 5 mm). Smaller holes appeared to clog too frequently and larger holes appeared to have substantially lower oxygen transfer. Short pipe nozzles consisting of 2-inch long tubes with 1/8-inch interior diameter were reported to have been used with some success.

Although mechanical aerators such as those reported by Schutz (789-91) have been successful in the fermentation industry, Trebler and Harding (1139) conclude that mechanical aerators of various types have not been entirely satisfactory for the dairy industry because of high up-keep costs. And on the basis of preliminary studies of their own, they commented that draft-tube aerators appeared to require excess power in relationship to the amount of air transferred.

Ejectors were reported to give excellent aeration with small volumes of air (1139). However, the oxidation/horsepower generally is larger than for drilled pipe diffusers. Ejectors were believed to tend to break up sludge particles too much and cause foam in the aeration tank and scum in the clarifier. Some plant operators still are concerned that their ejector aeration devices are a potential source for breaking up the flocs, for they frequently note pinpoint flocs and rising flocs in their system. However, Kountz (584) has maintained that the jets do not cause sludge problems.

In an earlier paper, Horton and Trebler (479) noted that it was possible for water to enter the headers of diffuser-type aeration systems during the periods of power failure. Operator comments during the industrial survey portion of this project indicated that when this occurred, the water often could not be adequately cleared from the header system. This appeared to be a problem for submerged headers such as those in aerated lagoons.

Kountz (590) evaluated the performance of several aeration devices for dairy waste treatment using sodium sulfite solutions. In this early study, neither K_La or α-values were determined. His findings indicate, however, that diffusers may transfer as much as 2-1/2 pounds of oxygen per horsepower as compared with 1.3 pounds for ejectors with blowers and 1 pound for ejectors alone. The better performance of the diffusers needed to be balanced against the "many reports" of clogging and need for monthly cleaning when diffusers are used in dairy waste treatment systems, he maintained.

Kountz (589, 586) found that the transfer efficiency, evaluated in sodium sulfite solution, is only about 1% for preforated pipe aeration system, about 2-5% for porous plates, about 17-25% for a specific ejector design, and perhaps as high as 40% when air under six pounds gage was supplied to a turbine type aeration system.

Hauer (441) reported that the efficiencies of aeration for jets and three other means of aeration used in dairy treatment processes vary from about 12-20%. Thus, the theoretical amount air required for each pound of oxygen absorbed was said to vary from about 320 to about 470 cubic feet at atmospheric pressure.

Wälholz and co-workers (1208a) have recently reported power requirements for a number of different activated sludge treatment systems as part of extensive case studies of milk waste treatment.

Ice buildup can be a serious problem for surface aeration devices in the Northern states. Floating surface aerators have been reported to capsize under heavy ice loadings in spite of four-way cable hawsers. Flail-type surface aerators may have mechanical drive problems under heavy icing conditions according to industrial reports.

Sludge Settling Characteristics

Poor sludge settling characteristics, and the formation of floating sludges or foams appears to be one of the major problems in the activated sludge treatment of dairy wastes.

Trebler and Harding (1138) had the opportunity to visit a relatively large number of dairy processing plants in conjunction with the dairy waste subcommittee in preparation for revision of the industrial waste guide for the milk processing industry. They noted that all plants checked at the time of their 1955 report had had voluntary or involuntary discharge due to foaming or poor settling of solids. Similar observations have been frequently reported in the literature and in field contracts. In their reviews Southgate (1040) in 1954 and Fisher (363) in

1968 have also indentified poor sludge characteristics leading to carry over as a major problem in the activated sludge treatment of dairy wastes.

The work of Pipes (815a) and Adamse (6) has provided a better definition of the sludge bulking problem. The studies of Quirk et al. (857a) and Fürhoff (381) have provided loading vs. performance data for systems containing whey. Most of the additional data are from European studies of oxidation ditches, hence are for low sludge loading levels.

Pipes (815a) constructed an atlas of activated sludge types which included studies for a large proportion of plants which had had a history of operating problems. This atlas included characterization of the sludge settling characteristics for two milk plants, one at Woodstock and another at Spiney Run, Illinois, and four plants that included large fraction of dairy waste along with domestic and other industrial wastes. (This study has been referred to before in this report in conjunction with the microflora of dairy waste treatment systems.)

Pipes' findings (815a) which are shown in Table 72 indicate a wide range of defects. The terms used in this tabulation are summarized in Table 73. As indicated in the summary, Table 74, the most predominant defect reported in the milk waste treatment plants and the second most prevalent defect in the combination plants was deflocculated sludge. (Here the supernatant suspended solids was larger than 30 mg/ℓ and the fluid was turbid.) The next most prominent defect was the occurrence of high suspended solids in the effluent accompanied by the occurrence of discrete particles in the effluent. At times this high suspended solids carry over, characterized as deflocculated or pinpoint floc, was accompanied by foaming or billowing. The least prominent defect is bulking as detected by high sludge volume indexes. Earlier investigators referred to sludge problems as bulking. They may well have been referring to the other two defects as well as the production of large sludge volume indexes.

For the same defect, the settling and compaction characteristics, and the sludge volume index value do not appear to be significantly different for milk as compared to milk combined with municipal wastes. The sludge settling compaction rate and and sludge volume index characteristics of pinpoint floc or deflocculant sludge do not appear to be significantly different than those for "normal behavior." There is some suggestion of larger sludge volume indexes, poor settling rates and larger compaction rates for bulking as contrasted to the other sludge classification.

Pipes (815a) commented that there does not appear to be much difference between the process loadings or process operation which produce normal sludge or pinpoint floc. Bulking was reported to occur in the same range of operating characteristics and loading, but all samples exhibiting bulking were reported with systems with no intentional wasting of sludge. (Thus this defect may be associated with long periods of sludge aeration and loss of enzyme activity for β-galactose metabolism

Table 72 - Operational Paramaters and Sludge Characteristics for Several Activated Sludge Plants Receiving Dairy or Dairy and Municipal Wastes, after Pipes (815a)

Plant	Type of Waste	Loading BOD/lb MLSS	Effluent BOD mg/ℓ	BOD Reduction, %	Settling Rate, mℓ/min	Compaction Rate, mℓ/min	SVI, mℓ/g	Supernatant ss (mg/ℓ)	Sludge Classification	Problems
Woodstock	Milk Wastes and C.C. Whey	0.053	292	87	67	0.67	115	303	Defloc	Foaming and loss of solids in effluent
		0.14	14	98	-	1.90	199	200	Defloc	Foaming and loss of solids in effluent
		0.13	10	99	-	0.50	150	181	Defloc	Foam, high solids in mixed effluent
		0.086	13	98	-	1.10	122	-	Bulking	Foam, loss of solids in effluent
Woodstock	Domestic and Dairy (30% of BOD)	0.15	11	87	80	0.64	38	59	Pinpoint floc	No dairy waste this sample
		0.02	22	59	450	0.01	50	66	Pinpoint floc	Loss of solids
		0.018	28	69	180	0.59	65	46	Pinpoint floc	Loss of solids
		0.019	20	79	145	0.44	67	43	Pinpoint floc	Loss of solids
Antioch, Illinois	Domestic and Dairy and Ink	0.29	73	52	124	0.70	79	110	Pinpoint floc	None
		0.21	7	97	210	0.72	54	36	Pinpoint floc	None
		0.31	9	97	145	0.35	46	21	Normal	None
		0.29	7	96	14	3.90	296	9	Bulking	Poor return, sludge capacity

Table 72 - Continued

Plant	Type of Waste	Loading BOD/lb MLSS	Effluent BOD mg/ℓ	BOD Reduction, %	Settling Rate, mℓ/min	Compaction Rate, mℓ/min	SVI, mℓ/g	Supernatant ss (mg/ℓ)	Sludge Classification	Problems
North Shore	Domestic and Dairy (Cheese)	0.85	15	97	240	0.38	44	62	Pinpoint floc	Billowing and septic sludge
		0.55	9	98	690	0.15	36	72	Pinpoint floc	Billowing and septic sludge
		0.22	9	95	1050	0.24	41	23	Normal	Billowing and septic sludge
		0.18	75	47	320	0.42	42	88	Pinpoint floc	Billowing and septic sludge
Spiney Run Illinois	Milk Wastes	0.23	632	56	352	0.77	162	266	Defloc	Continuous loss of sludge in secondary clarifier
		0.29	19	97	370	0.32	59	11	Normal	Continuous loss of sludge in secondary clarifier
		0.43	241	17	-	0.53	263	73	Defloc	Low solids in aeration, high solids effluent
		1.10	369	45	-	-	36	178	Defloc	Low solids in aeration, high solids effluent
Milton, Wisc.	Domestic and Milk Recv. Plant Wastes	0.78	70	74	880	0.11	82	51	Defloc	Loss of solids from clarifier
		0.30	46	64	285	0.45	148	48	Defloc	Loss of solids from clarifier
		0.50	30	91	176	0.67	250	63	Defloc	Loss of solids from clarifier
		0.52	14	90	48	1.95	946	16	Bulking	Low solids in aeration tank

Table 73 - Sludge Classification Used by Pipes(815a)

Term	Sludge Volume Index (mℓ/g)	Supernatant SS (mg/ℓ)
Normal	< 100	< 30
Bulking	100 < SVI < 300	< 30
severe	> 300	< 30
Deflocculated	-----	> 30 turbid
Pinpoint floc	-----	> 30 discrete particles

Table 74 - Summary of Activated Sludge Settling and Performance Characteristic for Plants Treating Dairy or Dairy and Municipal Waste, for Data of Pipes (815a)

Waste	Sludge Classification	Loading BOD lb MLSS			Effluent BOD, mg/ℓ			BOD Reduction, %			Settling Rate mℓ/min			Compaction Rate mℓ/min			SVI mℓ/g			Supernatant ss (mg/ℓ)			No. Obs.
		Av.	Range		Av.	Range		Av.	Range		Av.	Range		Av.	Range		Av.	Range		Av.	Range		
Milk	Normal	.29	---	----	19	---	---	97	--	--	370	---	---	.32	----	----	59	---	---	11	--	---	1
	Defloc	.35	.05**	1.10	10	260	630	16	17	98	210*	?	352	.90	.5	1.9	150	35	200	200	70	300	6
	Bulking	.09**	---	----	12	---	---	98	--	--	---	---	---	1.10	----	----	122	--	---	---	--	---	1
Combined	Normal	.27	.2	.3	9	9	9	96	95	97	600	145	1060	.3	.2	.35	43	41	46	22	21	23	2
	Defloc	.6	.3	.7	50	30	70	76	64	91	450	150	880	.4	.1	.7	160	80	250	55	50	63	3
	Pinpoint Floc	.25	.02**	.9	30	7	75	76	47	87	270	80	690	.45	.01	.7	50	35	90	65	43	110	9
	Bulking	.4	.3	.5	11	7	14	93	90	96	30	15	50	2.9	2.0	3.9	620	300	950	13	9	16	2

*Most data missing.
**Later industrial contacts indicate higher loadings than those observed in Pipes study.

(1007, 1278).) Deflocculated sludges were found predominantly for systems with relatively high loading rates but were found at lower loading rates as well. Pipes suggested (815a) that loading rate may be a factor, but that there appears to be other causes as well.

The sludge characteristics may not correspond to the loading and effluent characteristics found by Pipes due to factors such as the substantial variability in hydraulic and BOD loading from these dairy facilities, high sludge ages and the seemingly relatively slow recovery of enzyme activity after wash-outs; two weekends or three-day holidays which are periods of low feeding.

Adamse (6) found that highly bulking sludges could be corrected by modifying the microflora through the introduction of poorly assimulatable carbon sources such as calcium acetate or calcium lactate and/or by the addition of an inorganic nitrogen compound along with the dairy waste. (His observations as to the possible causes of bulking in dairy wastes has been discussed earlier in relationship to the microbiology of dairy wastes.) If his proposed mechanism is a prime cause of bulking for otherwise satisfactory operating conditions, then greater sludge problems might be expected when whey was present in significant quantities.

Porges and Jasewicz (831) made one extended fermentation of both supplemented and unsupplemented whey which indicated a larger loss of COD through nonsettleable sludge (probably pinpoint or deflocculated sludge) for the N-supplemented whey.

Quirk et al. (857a) made extensive studies of combined whey, (1.55%) dairy 0.09 and domestic activated sludge (15.90) waste treatment in laboratory systems at constant feeding rates. They repeatedly noted problems of sludge bulking.

In preliminary studies with 15 gallon, activated sludge units at loadings of 0.2 and 0.4 pounds skim milk BOD/pound sludge, the sludge volume index rose from about 340 ml/g with fresh domestic seed to about 850 ml/g for acclimatized system. When whey and sewage were added instead, the sludge volume index rose to about 1,500 ml/g.

When new domestic seed was used for the simulated whey-domestic waste the sludge volume index fell from about 340 to about 190 ml/g at a loading of 0.1 pound BOD/pound sludge and rose to about 1100 ml/g for a loading of 0.2 pound BOD/pound sludge.

The poorer performance for acclimatized sludge is in agreement with industrial reports that accidental whey discharges could be adequately treated, but upon continuous whey discharge performance often deteriorated.

Later studies (857a) on the same waste gave sludge volume index values of about 900-1300 for unsupplemented waste removal velocities of about 0.2 to 0.46. Sludge volume indices for NH_4-supplemented waste were about 100, 1950, and 380 ml/g for BOD removal velocities of about 0.08, 0.47, and 0.68 pound-BOD_5/pound sludge per day, respectively. (See figures 48 and 49).

Quirk et al. (857a) report the settling characteristics of a sludge produced during laboratory-scale extended aeration. The sludge with a 788 ppm initial concentration settled at a rate of about 530 ml/min and compacted to about 11,200 ppm at a rate of 0.6 ml/min.

Fürhoff (381) has reported sludge volume index values substantially below those reported in the study by Quirk (857a). However the data shown in Table 75 are for a system in which ferrous sulfate was added as a coagulant. Also the entire experiment was conducted over a relatively short period of 35 days (including 5 days acclimation). The study of Quirk et al. (857a) and those of Adamse (6) suggest that this may not have been sufficient time for acclimatization.

The addition of ferrous sulfate might be expected to influence the overall treatment process in a number of ways:

1. Potential shift in microflora, for the growth of psyschrotropes and yeasts are enhanced by the addition of iron.

2. Removal of a portion of the lactose.

3. Possible interference in the binding of the surface active whey protein β-lactoglobulin with the biomass.

4. Possible biomass flocculation aid (1104a, but not for Zoogloea species (189a).

Chemical coagulation methods such as the Guggenheim process (400a, 803a) fermentation following the addition of coagulants, and pH adjustment have been used in the United States, Great Britain and Europe (560, 1036, 1040, 1273, 1049, 429, 363) but have fallen into disfavor except in Europe due to added costs, greater sludge volumes, more control needed, and in some instances, deterioration of sludge filtration characteristics (1238, 1273, 990, 429, 741, 328, 1008, 439, 1138).

Kountz (580) has reported that the pilot plant operation on dairy plants effluent at Pennsylvania State University yielded sludge volume index values between 40 and 50 corresponding to a settled sludge volume of 0.8 $ft.^3$ per pound of sludge. This value which was later used in the USDA Handbook #176 (834b) is in general agreement with the sludge volume indexes for normal sludge as shown in Table 74.

Table 75 - Operational and Sludge Values for a Milk, or Milk Whey Wastes with Ferrous Sulfate Added at a Rate of 150 g/m^3 (after Fürhoff)

Waste		Temperature, °C			pH		O_2	$KMnO_4$, ppm		BSB_5, ppm		Reduction, %		Loading*	Sludge			Remarks
Milk ℓ/day	Whey ℓ/day	Air	Inlet	Outlet	Inlet	Outlet	Outlet	Inlet	Outlet	Inlet	Outlet	$KMnO_4$	BSB_5	BSB_5 kg/m^3	Set Vol. mℓ/ℓ	Dry m. g/ℓ	Index mℓ/g	
10	--	10	--	--	6.8	6.5	--	1990	316	--	--	84.5	--	--	70	1.61	43.5	
11.5	--	6.5	5.5	5.7	6.9	6.5	--	1896	306	--	--	84.0	--	--	110	2.10	52.5	
7.0	--	6.0	7.4	7.2	6.5	6.9	13.7	1422	159	--	--	89.0	--	--	170	2.24	76.0	
7.0	--	1.5	9.2	5.2	6.8	7.0	12.0	1454	126	--	--	91.5	--	--	150	2.46	61.0	
8.2	--	1.5	9.0	4.8	6.8	7.0	15.6	1359	79	510	10	94.2	98.0	0.25	190	2.64	72.0	
7.0	0.35	1.7	8.5	5.5	6.6	6.9	--	1106	79	571	52	93.0	91.0	0.285	220	2.85	77.2	
7.0	0.35	8.0	9.2	9.0	6.7	7.0	11.0	--	--	--	--	--	--	--	250	3.24	77.2	
7.0	0.35	12.0	11.0	13.0	6.5	7.3	9.1	--	--	--	--	--	--	--	300	3.54	85.0	
7.0	0.35	4.0	9.0	8.2	6.5	7.5	11.0	--	--	--	--	--	--	--	320	3.58	89.5	
7.0	0.35	5.0	10.2	6.0	6.5	7.2	13.0	1288	63.2	418	11	95.0	97.3	0.21	370	3.88	95.5	
7.0	0.35	4.6	10.2	5.7	6.5	7.0	13.0	--	--	--	--	--	--	--	320	4.06	79.0	With 21.8 g fat/liter
7.0	0.35	6.8	10.0	7.0	6.5	7.2	11.7	--	--	--	--	--	--	--	340	3.96	86.0	
7.0	0.35	--	--	--	--	--	--	--	--	--	--	--	--	--	500	4.24	118.0	With 22.6 g fat/liter
10	0.5	4.5	9.4	7.4	6.8	7.0	10.4	1896	63.2	--	--	97.0	--	--	240	3.88	62.0	
10	0.5	8.0	10.0	7.8	6.8	7.2	8.4	--	--	--	--	--	--	--	450	4.70	96.0	With 23.0 g fat/liter
10	0.5	5.0	9.8	8.6	6.8	7.0	6.5	1890	107.4	417.9	48.1	94.5	88.5	0.21	260	1.80	144.0	
10	0.5	2.6	9.6	5.7	6.8	7.0	10.4	--	--	--	--	--	--	--	430	4.64	92.6	
10	0.5	10.6	10.5	9.7	6.8	7.0	9.8	--	--	--	--	--	--	--	240	4.90	49.0	
10	0.5	9.5	10.2	11.0	6.5	7.5	8.5	2496	379	--	--	85.0	--	--	310	3.60	86.0	
10	0.5	9.8	10.5	11.0	6.2	7.5	4.0	--	--	--	--	--	--	--	400	4.35	92.0	Without ferrous sulfate
10	0.5	8.2	9.5	10.0	6.8	7.6	6.5	2654	158	725.9	19.0	94.0	97.3	0.36	460	4.20	109.0	
10	0.5	7.0	9.7	10.0	6.6	7.5	5.2	--	--	--	--	--	--	--	620	4.23	146.0	With 23.0 g fat/liter
--	--	12.0	--	13.0	--	7.3	3.9	--	--	--	--	--	--	--	560	4.60	122.0	

*One kg/m^3 is equivalent to 62.3 lb/1000 ft^3

These studies (834b, 590) also showed settling velocity, V_s, of 2 to 8 feet per hour depending on concentration

$$V_s = 10.8 - \frac{\text{ppm sludge}}{950} \qquad [25]$$

Nehrkorn and co-workers (751, 873, 1276) have reported on the sludge characteristics of three different oxidation ditch systems, in comparison with the results of Muskat (747a). Their results are summarized in Table 76.

Table 76 - Sludge Characteristics for Oxidation Ditches, after Nehrkorn and Replok (751, 873), Muskat (747a), and Wöste and Nehrkorn (1276)

	A	B	C	M	ω
Loading, 16 BOD/1000 ft. , day	11.2	22.5	9.4	16.2	-
16 BOD/1b., day	.05	.052	.02	0.028	-
Sludge Vol. (30 min.) mℓ/ℓ	800-900	830-980	870-980	-	320
Dry matter g/ℓ	40-7.1	3.6-8.0	8.4-11.2	3.6	5
Organic %	60-69	62-82	76-84	-	-
Index	× 120	< 200	× 100	< 100	60

Wheatland (1240) reported experiments with activated sludge treatment of dairy wastes at the Water Pollution Research Laboratory in Great Britain. In initial experiments with BOD loads of about 155 pounds of BOD per 1000 ft.^{3} in a contact plus aeration system with a corresponding volumetric loading of about 10,000 gallons per 1000 ft.^{3} per day difficulty was soon experienced with bulking of activated sludge. A reduction of BOD loading to about one third prevented further deterioration of sludge characteristics. Subsequent return to this loading level lead to the original bulking condition once more. He reported that laboratory observations indicate that bulking of activated sludge fed with domestic sewage is troublesome and that bulking is not experienced for low loadings and high loadings. Thus they increased the load of their plant three-fold to 31,000 gallons per 1000 ft.^{3} per day and BOD loads of 470 pounds per 1000 ft.^{3} per day. Then the system had a contact time of 1.6 hours and a sludge aeration time of 3.1 hours. The mixed liquor concentration was 8000 parts per million, giving a sludge loading of about 0.6 pound per day per pound of solid. Under these operating conditions, the sludge volume index decreased to a value in the range of 50 to 100.

Boone (182) has reported sludge volume indexes of 85, 64, and 77 at BOD loadings of 0.52, 0.83 and 1.16 pound milk waste BOD/pound of suspended solids per day, respectively. During the higher loading the temperature was about 25°C instead of the earlier 20°C. Further, Boone reports that the sludge volume index remained below 100 mg/ℓ during the entire period except for one observation of 150 mg/ℓ and that the average sludge volume index was about 75 mℓ/g. Because of this low value of sludge volume index they are able to maintain activated sludge concentrations of from 4,000 in the initial stages to around 14,000 in the later stages of their investigation.

Fisher (363) suggests that the incidents of bulking appears to be less on sewage and other systems, perhaps even dairy systems, that have either relatively high or relatively low sludge loadings.

The data presented above tend to support this view, but no one study has explored the entire range of loadings for milk waste.

Control of sludge characteristics in the presence of moderate amounts of whey appears to need further study. The approaches of Adamse (6) and Fürhoff (381) are possible directions, including resolution of the influence of supplementation as reported by Quirk et al. (857a), Porges and Jasewicz (831) and Kountz (591).

Sludge Filtration

Boone (182) studied the specific resistance to filtration of activated sludge from their dairy-whey treatment system. Sludge taken from the reaeration zone following waste contact had specific resistances of 10^8 to $10^9 s^2/g$. Further tests with a filter press indicated that sludge with a specific resistance to filtration of less than $10^7 s^2/g$ could be dewatered without the addition of coagulant chemicals. However, up to 1% of aluminum chlorohydrate on a dry basis were found necessary for filtration if the value of the specific resistance of the raw sludge increased to about $5 \times 10^9 s^2/g$.

After 10 days continual operation the aerobic sludge digester zone of their pilot contact-stabilization plant had sludges with specific resistances as large as $14 \times 10^9 s^2/g$. Such sludges were very difficult to dewater and the addition of coagulant chemicals failed to improve this specific resistance significantly.

Boone (182) concluded that inclusion of an aerobic digester in an activated sludge plant would bring about significant deterioration in the filtration characteristics although it would significantly decrease the sludge concentration. On the basis of a literature review by Hopwood (unpublished) he suggested that a continuous, rather than a batch-wise digester, might give sludge with improved specific resistance to filtration as well as reduced concentrations.

Quirk et al. (857b) referred to their unpublished studies of dewatering of whey-dairy domestic sludge which indicated that these sludges were not amenable to dewatering by either water vacuum filters or centrifuge. Numberical values of process parameters and flow sheet were not given.

Flotation

Quirk et al. (857b) investigated the feasibility of flotation of an activated sludge liquor on bench scale equipment for a combined dairy whey municipal waste. They reported a design overflow rate of 600 gallons per day per square foot based on untreated waste flow. They concluded that flotation would not be economically competitive in comparison with sedimentation.

On the Foam Problem: Our observations in the field indicate that the foams reported by Pipes (815a) may be of one of two types: Type 1, a fluffy, low-density, low-shear strength foam which has been referred to as billowing foam, or Type 2, a dense, high-shear strength, stable foam. This second foam has sufficient rigidity to require dissolved oxygen or other probes to be forcibly inserted.

Porges et al. (834b) note that excessive foaming has been a problem at times. They maintain that foaming does not generally occur when the waste is being added, but toward the end of assimilation period.

This would correspond to the observation that carbohydrates tend to accumulate from a polysaccharide exterior to a microbial cell during periods of effective nitrogen deficiency (6). For dairy wastes, this would likely occur at the end of a three- to six-hour assimulation period. It might also be possible for such an overfed system to give even greater foam if the sludge were brought in contact with high concentrations of new waste. At this time, the carbohydrate surface would be free to interact with the relatively large concentration of surface active serum proteins.

Hoover and Porges (584) report that such a foam showed a composition of 30,000 ppm solids, 2,700 ppm ash, 9,3000 ppm "protein," 1,350 ppm reduction sugars, -7 percent water soluble, and a strong test for dextrins.

Analysis in our laboratory of a Type 2 foam revealed that the solids contained about one-third β-lactoglobulin and the remainder was microbial cell mass.

Kountz, Hoover and Porges (584) found this type of foam during an abnormally high production of cheese. During the foaming they observed,

(1) Reduced redox potential (-400 mV) in the presence of dissolved oxygen,

(2) negative bacteriophage tests,

(3) slight decrease in total plate count (68°F) and motile organisms, with some yeast cells present, and

(4) slight increase in surface tension above normal of 68°F.

Kountz (584) reports that the foam was not influenced by (a) stoppage of the air for 24 hours, (b) dilution with fresh waste after initial stages, (c) storage for several days, or (d) water spay or steam, but was reported controlled by reduction of the aeration rate, with ejectors, from 2 to 1 cubic foot per minute per pound BOD.

Preliminary laboratory studies of laboratory scale activated sludge treatment of skim milk, whole milk cheddar cheese whey, and cottage cheese whey individually did not show the type foaming. Silicone antifoams were used. No experiments for fermentations without antifoams were reported.

Later addition of controlled amounts of whey did not cause foaming. The aeration rate was 1 cubic foot per minute per pound BOD.

Industrial reports suggest (1) increased likelihood of foaming in the presence of whey or whey wash water especially at high sludge loads, (2) the occurrence of foam primarily at the end of the assimulation period but also in the initial contact region for a plug flow extended aeration system, (3) some advantage to reduced aeration but often with a significant increase in sludge defects, (4) no practical advantage to antifoam materials, (5) no practical advantage to NH_4 supplementation and (6) the need for a means of removal and separate disposal of the foam which does form so that the operator may observe the response of the system to corrective measures without being distracted by the foam, and also so that the stable foam does not wind up in a water course.

Neither the industrial reports or the preliminary reports cited were performed with adequate controls, or replication. Frequently the industrial reports are confounded by the practice of making several simultaneous changes. Identification of the mechanism of this foaming and development of control measures are needed.

Porges et al. (834b) also suggest that foaming may be caused by overaeration and that unless unnatural materials are present that this foaming will usually subside when aeration is stopped or substantially reduced.

Kountz (590) has reported that it is necessary to eliminate the air supply from that required for the assimilation phase when waste flow ceases or else foaming problems will be encountered. This probably is Type 1 foam.

Loss in Sludge Activity

Siddiqui (1007) reported that the substrate removal capacity of sludges can be substantially reduced with prolonged stabilization and suggests that this loss in capacity is associated with a loss due to inactivation of inducable enzymes systems associated with the metabolsim of lactose.

Porges et al. (830a) maintained that sludge in good condition may rest six hours without deleterious effects if it is then aerated for approximately one-half hour. They further commented that they did not know how much longer sludge could be maintained aerobic.

Industrial experience indicates that sludge activity may be lost during shut-downs such as those experienced over week-ends and that some loss may be even experienced during one day down-periods for holidays. There have been attempts to maintain activity by substantially reduced aeration accompanied by slow metering in about a half-day waste load during the expected down time.

Experiences with Whey Treatment: Whey-containing wastes have been treated with varying success as is indicated in some brief experiences summarized below. Problems in treatment of such wastes led some observers to prefer alternating double filtration and Quirk et al. (857b) to develop a high rate trickling filter design instead of an earlier activated sludge approach (857a).

Wheatland (1238) has reported that milk waste could be satisfactorily treated by an activated sludge process but that whey-washings with a BOD strength of 660 ppm required 36 hours of aeration as contrasted to the 24 hour aeration of 352-500 ppm of milk waste. He further reported that mixtures of milk and whey washings at a BOD strength of 710 ppm yielded equally good effluence when aerated for either 24 or 36 hours.

Wheatland (1238) also reported operational problems with activated sludge treatment of whey washings, milk waste and combined waste. The primary difficulties were rising and bulking of sludge. He maintains that rising of the sludge was usually associated with the presence of high concentrations of nitrite and nitrate in the final effluent and could be prevented by either increasing the loading rate or by decreasing the period of aeration. He further commented that bulking usually occurred when the period of aeration was too short or the loading too great.

Kountz (591) has commented,

> "Whey can be treated as easily as milk solids providing one precaution is observed. Whey itself has no property that interferes with its assimilation by a biological culture. It is simply a 6% solution of lactose. Bacteria, unlike human beings, do not

> assimilate sugar for pleasure. They convert casein to new bacterial cells and assimilate the lactose for the necessary energy to do this. Unless sufficient casein or some form of nitrogen is present the whey (lactose) will remain untouched by the culture and thus the waste will be untreated. The addition of six pounds of ammonia or its nitrogen equivalent to the treatment plant for each thousand pounds of whey will allow the culture to assimilate whey immediately."

Trebler and Harding (1138) reported that activated sludge treatment of waste containing a relatively large proportion of whey, particularly deproteinated whey, could be helped by the addition of assimilable nitrogen compounds. The observation was made that this appears to improve sludge settleability and effluent quality.

Porges et al. (8346) have noted that the addition of the equivalent of 700 pounds of whey solids per week for a plant designed to handle 2100 pounds of milk solids for the same period did not appear to interfere with aeration process and that the most noticeable effect was an accumulation of sludge. They further noted that accidental discharge of a large quality of whey was observed to produce excessive foaming with consequent incomplete purification. They suggested (8346, 516) the addition of one pound of ammonia nitrogen, i. e., five pounds of ammonia sulfate per thousand pounds of liquid whey to give a COD nitrogen ratio of approximately 20:1. This is contrary to the observation by Porges et al. (831) for their extended fermentation of supplemented vs. unsupplemented whey systems. They concluded that there was no advantage to the addition of NH_4 nitrogen.

Treatment of whey wastes is of such great concern (602) that a number of demonstration studies are in progress. Basic mechanisms and control measures may be forthcoming.

Activated Sludge Performance Data

Activated sludge treatment has been extensively applied to the treatment of dairy wastes for several decades. Often these systems have been used to try out new aeration approaches, newer process flow schemes or, in case studies of operational problems, often those encountered with whey. Thus, there have been many literature reports of these systems. These reports span the period of immergence and growth of the discipline of sanitary engineering. Too, these reports often reflect best judgment based on industrial experiences rather than upon detailed performance evaluations. As a result many reports are fragmentary and nearly all report no treatment kinetic data.

Performance data have been extracted from many of these reports, often involving calculations using data supplied to more nearly complete the performance characterization. The results of this analysis are shown in Table 77 for activated sludge and in Table 78 for oxidation ditch systems. (Additional performance data has been presented previously in Tables 72, 75, and 76, with respect to sludge characteristics.) Efficiency data from the industrial survey are presented in Table 79.

A number of process variations have been used including fill and draw, extended aeration, single well-mixed tanks, a series of well-mixed tanks and others.

Generally, the average BOD of the influent reported for the studies were one-half to one-tenth of the BOD found in our industrial survey. Lower BOD values may reflect either higher water usage or better control which often, but not necessarily, follows from the operation of a treatment plant.

The treatment efficiency values reported vary from about 25% to over 99%, with an average removal efficiency of about 85%. Many efficiency values reported are "averages" based on grab samples for periods of "normal" operation. Also, it is difficult to obtain a reasonable estimate of the effluent BOD contributed by stable forms. Available data on the day-to-day operation of individual treatment systems, such as shown in Figures 42-44, indicates that there may be a great deal of day-to-day variation in system performance depending upon the supervision and capacity of the system. As a result, management guidelines might well include not only target average treatment efficiencies but at some future time a goal of a minimum treatment efficiency every 90 days. This later step will be feasible when instrumentation is available to measure performance on line and sufficient treatment system knowledge is able to permit not only feed-back but feed-forward controls; feed back-forward controls because there is little an operator can do to bring the system quickly back to nominal process values when confronted with Type 2 foam or multiple sludge defects.

Often the BOD concentrations reported are less than 15% of the mixed liquor suspended solids. Further, the mixed liquor suspended solids levels range from 300 ppm in the treatment systems to over 10,000. These highly mixed liquor suspended solids levels may be the result of a large sludge production and may be particularly difficult to maintain in the frequently encountered bulking conditions noted with dairy wastes. The data did not indicate that low volumetric loading or highly mixed liquor suspended solids levels in themselves are helpful for maintaining the desired efficiencies. In fact, visual inspection of the tables indicates that a principle factor influencing the efficiency for these studies appears to be the retention period in the aeration unit. This is surprising because the laboratory data of Hoover and Porges and co-workers indicates that substantially all the COD or BOD is associated with the biomass after the first one-half to three hours of aeration and that relatively little BOD or COD is present in the clarified (centrifuged) effluent. The sensitivity of

Table 77 - Performance of Activated Sludge Treatment Systems

Process	Influent, BOD_5, ppm	Effluent, BOD_5, ppm	% Reduc. BOD_5	Flow mg/d	BOD_5, lb/1000 ft^3	MLSS, ppm	Aeration, ft^3/lb	Detention, hr.	Return Sludge, %	Remarks	Ref.
Cheese factory spraying, lagooning activated sludge	6,000 10,000	10	> 99.8	.15	-						(102)
Milk processing	1500	20	98.7	-	30-60						(108)
-	-	-	97	-	-		1 cfm/#BOD	30 aer. 2 set.			(SA 30) (168)
Dried milk, condensed milk	1440 3000 3000	440 1100 960	69 63 68	- - -	- - -	9000 7700 10,700	- - -	1.6 aer. 1.7 aer. 1.7 aer. reaer. 2X	- - -	Contact stab. in pds.I&II .	(181 * 182, 12-0)
Dairy waste	-	-	97 85-90	- -	18 .06-0.09	- -	- -	- -	- -		(194)
Cheese factory	2000 3300 2300 750	1300 1700 330 5	37 48 85 99.4	0.008 0.004 0.010 0.017	111 83 53 37	- - - -	- - - -	- - - -	- - yes yes	Aer. only Aer. only Aer. set. Aer. set, sl.stor.	(262)
Milk receiving	240	18	92.7	0.009	8.7	-	-	-	yes	Equil, aer. set.	(262)
Cheese factory (excludes most wastes) (Guggenheim)	-	229	-	-	-	-	-	4.5	-	Max. BOD handled 3000 ppm	(328)
Casein factory Mallory	442-2800	1-26	99.0	0.048	-	-	-	2.6-3.1 aer, 1.4-1.5 clar	200		(329)
Milk wastes from bottle milk, ice cream, cottage cheese	860	6	99.3	> 0.14	-	-	-	-	-	Mallory	(331)
Cheese	940	9	99	0.025	-	5000-6000	-	21 Total (2 tanks)	-	Aerated balancing tank	(399)* SA 1272*
Bottling, cheese dried milk	528	10-63	88-98	-	-	1600-4900	-	23 aer. 3/4 set. 1/4 drain	-	Fill & draw	(381)*

Table 77 - Continued

Process	Influent, BOD_5,ppm	Effluent, BOD_5,ppm	% Reduc. BOD_5	Flow mg/d	BOD_5, lb/1000 ft^3	MLSS, ppm	Aeration, ft^3/lb	Detention, hr.	Return Sludge %	Remarks	Ref.
Milk	510	10	98.0	-	15.6	≈ .28 lb/lb day	≈ 5600 (3.3') ≈ 1800 (10.3')	-	NA	F + O 190 mℓ/ℓ; 72 mℓ/g 4.8°C	(382)
7 parts Milk .35 parts Whey	571	52	91.0	-	17.7	≈ .28 lb/lb day	≈ 5600 (3.3') ≈ 1800 (10.3')	-	NA	F + O 220 mℓ/ℓ; 77 mℓ/g 5.5°C	(382)
7 parts Milk .35 parts Whey	418	11	97.3	-	13.0	≈ .28 lb/lb day	≈ 5600 (3.3') ≈ 1800 (10.3')	-	NA	F + O 370 mℓ/ℓ; 96 mℓ/g 6.0°C	(382)
10 parts Milk .5 parts Whey	418	48	88.5	-	13.0	≈ .28 lb/lb day	≈ 5600 (3.3') ≈ 1800 (10.3')	-	NA	F + O 260 mℓ/ℓ; 144 mℓ/g	(382)
10 parts Milk .5 parts Whey	726	19	97.3	-	22.4	≈ .28 lb/lb day	≈ 5600 (3.3') ≈ 1800 (10.3')	-	NA	F + O 460 mℓ/ℓ; 109 mℓ/g	(382)
Town's dairy	1472	2.9	98	-	-	-	2 CuH/gal	-	-		(388)
Dairy waste	1000	> 10	< 99	-	-	-	3600	-	-		(429)
Dairy waste treatment plant	800-1200	8-30	97-99	-	-	-	500-800	28-40	-	1 hr set.sludge vol. 40-90%. Lowest op. temp. 72°F.	(429)
Milk wastes	-	-	71-77%; 96-97%; 69%	- - -	1.0 0.6 0.96	- -	44, c/m 44- 84 c/m	- - -	- - -		(438)
Maplehurst	1100	9-124	70-98	0.007-0.016	- -	- -	(36 cfm) (8-8.6% absorption, 02)	21 -48	-		(440)
Huntley, Dairy	936	172	67-97	0.015	- (8.5-10h)	-	1045 DO 1.0 to 6.0	21 aer. 3.3 set.	-	Light floc, air lift diffusers [(1100 cf/# jet desired)]	(440)
Chemung, Dairy	1150	-	75-85	0.053	-	-	(264 cfm) 759	14:7		jets	
Dairy	300	20	93	0.001	-	-	-	-	-	39 kwh/day	(549)
Dairy waste pilot plant	950 10,000 15,000 whey	86	90	0.015	-	-	10% air loading 1/6 of aer.	19 aer. 1 set. 11/2 drain 2 1/2 hr reaer.	-	Foam problem, TS 30,000-2700 ppm ash, 9300 ppm protein, 1350 ppm reducing sugars 0-50 influent COD Temp 50-90°F, pH 7.0-7.6	(584)*
Dairy waste some whey	10,000-15,000	< 50	90	0.01	-	-	-	-	-		(584)
Dairy plant	1600	72	95	0.025/ 8 hr.	-	5500	DO 0.6 -3.5ppm	-	-	Tank volume 37,500 gal Sludge vol 20-30%	(586)

Table 77 - Continued

Process	Influent, BOD_5,ppm	Effluent, BOD_5,ppm	% Reduc. BOD_5	Flow mg/d	BOD_5, lb/1000 ft^3	MLSS, ppm	Aeration, ft^3/lb	Detention, hr.	Return Sludge, %	Remarks	Ref.
"Dairy"	2200-3950	110 197	95	.007-.012	-	-	-	-	-	Precipitation of sludge	(641)
Cheese & dried milk	800-2500	< 10	-	0.01-0.18	-	-	-	-	-	Plant designed for 60,000-100,000 (max. 20,000) gal/day	(653)
Cheese plant, "A"	2000	1230	37	0.008	14	-	(51 cfm) 588	28.5	-	No settling	(678)
"B"	1950	610	69	0.153	15.5	-	(70 cfm) 387	25.3	-		
"C"	1230	428	65	0.07	7.6	-	(70 cfm) 600	32.3	-	No settling	
Dairy	-	20-25 SS 30-50	77 COD	-	-	-	-	-	-	Low pressure aeration, 10-20 mg nitrate/ℓ	(711)
Dairy	545	7	98	0.05	-	-	-	-	-	pH eff. 7.3-8.1, TS ppm infl 797, TS ppm eff. 466	(721)
Bottling	740	15	98	-	-	5600	Single mixed	20	-	Exp. unit, dil. skim milk as infl.	(745)*
	740	22	97			4800		12			
	710	64	91			6000		8			
	680	88	87			6300		4			
	860	220	74			7300		2			
	810	81	90	-	-	2200	Aer. set	20	-	Exp. unit, dil. skim milk as infl.	(745)*
	500	155	69			6100		15.5	-		
	480	96	80			3100		6			
	620	470	24			2200		5.2			
Cheese plant	1400-2000	19	99	0.02	-	-	-	-	-		(752)
Dairy	770	63	92	0.02	-	-	-	-	-		(794)
Cotton mill & dairy wastes	-	-	94	-	-	-	-	-	-	Lab exp 2 stage activated sludge	(802)
Milk bottling plant	5600	54	96.5	0.017 (16 hr)			0.35 cfm/lb	-	-		(844)
Ice cream factory (spring & summer)	2500	-	-	0.16-0.19	1.4 3.4-4.	- -	- -	-	-	Single stage Two stage	(942)
Bottling	550	55	90	0.07	-	-	Single, mixed	14	-	Aerated balancing tank	(959)*

Table 77 - Continued

Process	Influent, BOD_5,ppm	Effluent, BOD_5,ppm	% Reduc. BOD_5	Flow, mg/d	BOD_5, lb/1000 ft^3	MLSS, ppm	Aeration, ft^3/lb	Detention, hr.	Return Sludge %	Remarks	Ref.
"Cheese" waste	750	-	57	-	265	-	480	6.3	-	Draft tube-rotor aeration	(961,
whey was	-2750		79		295		430	8.0		No sludge return	962)
condensed			76.3		400		317	8.0			
			69		143		880	10.5			
			89		158		805	15.8			
			98.6		107		1180	31.5			
			99.6		232		545	45.0			
	332	-	98.1	0.09	775	-	775	15.4	-	2 stage, no cont. sludge	
	530		98.1	0.09	485		485	15.4		return, also 2.9 hr.settling	
	600		96.7	0.09	428		428	15.4			
	680		91.8	0.09	380		380	15.4			
	900		91.3	0.09	288		288	15.4			
	1240		90.0	0.09	208		208	15.4			
Cheese	1310	13-	95-99	0.008	-	-	2 mix in aer	15	-	0.4-0 8 m^3 sludge removed	(964)
Cheese waste	1705 -3820	15-20		-	-	-	-	-	-	Lab and pilot studies most nitrate & nitrite removed	(1001)
Dairy											
Belle Center	936	11	97 -99	-	-	-	(750 cfm)	10 aer, hold 23 aer. 19 set	600- 700	2 tanks, 2 clarifiers	(1108) (440)
New Bremen	-	-	98.9	0.03	-	-	(263 cfm)	2 mix lime 2 ps 41 aer. 4 set.	-	Excess sludge irrigated	(1108, SA 439, 399, 440)
Germantown (Schell) one shift	567	19	97 -98	0.0044	-	3640	(85 cfm) 6070	15.5 aer. 15.5 aer. 2.5 set.	500 -700, 200	No sludge withdrawl, swing diffusers DO 4.5-2.6, aer, 1-0 eff.	(1108-1111, 262, 440)
Dayton (Blossom Hill) one shift	926	31	97 -98	0.007 - .008	-	-	(100 cfm) 3750	10 aer. hold 37 aer. 3 set.	400 -500, 170	2 tanks series. No sludge withdrawal	(1108-1111, 262, 440)
Toledo (Cherry grove)	-	-	-	-	-	-	(100 dfm)	3420 aer. hold 12,300 aer. 970 set.	-	2 tanks (gals) Design data only	(1108)
Bottling	930 570	28 57	97 90	0.006 0.004	- -	- -	2 mixed tanks	41 34	- -	Aer. bal. tank	(1008) (SA 1272)

Table 77 - Continued

Process	Influent, BOD_5,ppm	Effluent, BOD_5,ppm	% Reduc. BOD_5	Flow, mg/d	BOD_5, lb/1000 ft^3	MLSS, ppm	Aeration, ft^3/lb	Detention, hr.	Return Sludge %	Remarks	Ref.
Dairy Oct.	400 -2200	8 -235	67 -99	25-58	98	300 -2800	-	47	-	1 day aerated preholding single tank	(1114)
Nov.	365 1600	8 - 60	91 -99	17-34	45	1800 -4000		43			
Dec.	237 -1800	7 - 27	90 - 99	34-34	57	1700 -6400		42			
-	-	-	82	-	-	-		24			(1116)
-	-	-	-	-	-	6000 -8000	1-4 vols/hr	-	-		(1117)
"Milk plant"	-	-	82 94 91	-	-	-	12 24 48	-	-	Pilot plant study well mixed system	(1123)
"Butter plant"	-	-	87 93 95	-	-	-	12 48 72	-	-		
Milk, yogurt, cheese, butter	1030 -1525**	105 -325**	79** -90	.016	-	-	-	-	-	9.1 hours/day, pH 6.2-7.0 "Aero-Accelator" (A)	(1208a) (1210)
Milk, butter, cheese	370 - 640	54 - 62	86.4	.019	-	-	-	-	-	14.6 hours/day, pH 6.4-7.5 "Aero-Accelator" (L)	(1208a)
Milk, butter Individual	320 - 410	-	82 -91	.006	20.9	-	-	21	-	2.2-22.5 hours use, pH 3.5 -12, 1 day holding Cap.(E)	(1208a)
70% dairy whey (Aqupure)	-	-	-	0.005	-	-	-	-	-	60 kwh/day, after 3 mo. serious bulking	(1209)
Bottling	822 620	22 222	97.3 64.4	.87 .85	-	-	ejectors 1 cfm/lb	49 50	-	Bulking, carrying over	(1228)
Dairy plant		-	99	0.007		-	-	-	-		(1234)
-	~ 1500 ~ 1500	- -	- 65	-	-	-	-	4.8 1.6 1.6	-	1 & 2 hr. waste cont. II. waste 8 hr. daily good settling only in III	(1239)
-	860 230 860	215 35 34	74 85 96	-	-	7300 1st 3900 2nd	2 mixed tanks int. set.	1st, 2 2nd, 4	-	Exp. unit.dil. skim milk	(1240)*

* From Fischer (363)
** COD Basis

Table 78 - Performance of Oxidation Ditches Treatment Systems

Process	Influent, BOD_5, ppm	Effluent, BOD_5, ppm	% Reduc. BOD_5	Flow, mg/d	BOD_5, lb/1000 ft^3	MLSS, ppm	Aeration, ft^3/lb	Detention, hr.	Return Sludge %	Remarks	Ref.
Dairy	-	-	-	-	15	4000	-	72	-		10
Bottling	180	17	91-95	0.024 - .026	-	-	Single Kessener	48	-	Presettlement	(208)*
Dairy	220	20	91	.008	4.4	-	-	75	-	Outerbasin 100 m^3, inner	228
	410	26	94	.009	8.7	-	-	71	-	basin $15m^3$	228
	580	17	97	.006	8.1	-	-	104	-	"	228
	760	27	96	.006	10.6	-	-	104	-	"	228
	667	31	96	.007	10.6	-	-	67	-	"	228
	703	30	96	.005	8.1	-	-	126	-	"	228
	545	31	95	.005	6.2	-	-	133	-	"	228
	462	17	96	.006	6.8	-	-	104	-	"	228
	348	20	92	.009	7.5	-	-	69	-	"	228
	Ca 600	Ca 21	Ca 96	.017	Ca 25	-	-	36	-	"	228
	534	34	94	.012	15.6	-	-	52	-	"	228
	392	14	96	.012	11.2	-	-	52	-	"	228
Dairy 1/4 vol Domestic	240 -15,000 5,200 av	20 -353 140 av	97.3	0.017	6.8			72	-	1.5 hrs settling, 1720 ft^2 sludge beds, 1 H sec at 132 rpm, 1.2 H/sec at 152 rpm, 2.6 H deep .46 lb BOC/lb sludge,day.	692
Dairy	-	-	-	-	11.2	.05 lb/ day	-	-	-	3.6 gram dy/ℓ	(747a)
Bottling	750 815	- 16	98	0.018 0.01	-	-	Ox.,ditch set	103 120 aer.	-		(790)*
Milk 25% Butter 65% Cheese 10%	- 1500 -2150	- 10 -16	- 98 -99	.009	10.3 Des 21 30	.02 lb/ lb,day	-	72 Des	-	Plant A; single; discont.; Sludge 800-900 mℓ/ℓ (30min) 4.0-7.1 g dry/ℓ	(873), 751)
Milk 25% Butter 75%	- 1300	- 8	99	.0118	6.6 Des 8 -11.2	.02 lb/ lb,day		320 Des		Plant B; double, discent; Sludge 830-980 mℓ/ℓ(30min) 3.6-8.0 g dry/ℓ	
Milk 36% Butter 62% Cheese 2%	- 1000 1600	- 3 -18	- 97 -99	.0158	11.2 Des 13 -18.6	.028 lb/ lb,day	-	135 Des		Plant C; double, discent; Sludge 870-980 mℓ/ℓ(30min) 8.4-11.2 g dry/ℓ	
Milk	211 224	4 7	98 97	- -	- -	4700 9200	Ox.,ditch	27 40	-	Exp. unit. dil. milk No excess sludge in 1	(931)*
Dairy	-	-	68	.015	41	-	-	73	-	Lexzno, Poland	(1084)
Dairy	-	-	92	.024	15	-	-	61	-	Boching	
Dairy	-	-	93	.008	51	-	-	108	-	Husow	
Dairy	-	-	96	.09	21	-	-	73	-	Garvolin	

Table 78 - Continued

Process	Influent, BOD_5,ppm	Effluent, BOD_5,ppm	% Reduc. BOD_5	Flow, mg/d	BOD_5 lb/1000 ft^3	MLSS, ppm	Aeration, ft^3/lb	Detention, hr.	Return Sludge	Remarks	Ref.
"D" Fluid Milk, cheese, Butter	620 -800	85 -165	74 -90	.01	18	-	-	58	-	pH 6.2-6.4, Brush	1208a
Milk, butter Cheese	-	-	-	.009	31	-	-	-	-	Roxel dairy	1276
Roxel dairy	-	20	-	.011 .012	31 Des -62 Opn	-	-	72 50-56	-	2.75 feet deep, 5' rotor, 75 rpm, 6 mo immersion, 1.1 H/sec Sludge 320 mℓ/ℓ vol, 5 g/ℓ dry, 60 mℓ/gm.	1276
Dairy	-	-	99.5	-	-	-	-	-	-	98.47 reduction S.S.; 94-98.1 reduction of N.	1285

Table 79 - Efficiency of BOD Removal by Biological Treatment of Dairy Plant Wastes - Industrial Survey Data

Plant	Secondary Treatment Method	Raw BOD		Treated BOD		% Reduction	
		Range	Ave.	Range	Ave.	Minimum	Ave.
1	Act. sludge + 2 stage aerated lagoon	600-760	680	20-50	35	91.6	94.8
		7500-17,500	1100	50-75	60	90.0	94.5
2	Act. sludge + 2 stage aerated lagoon	700-1500	1225	10-40	20	94.8	98.3
		Note: On site visit-day before act. sludge treated waste = 600 ppm (Raw BOD = 2500 ppm) 76% efficient; effluent from lagoon 60 ppm-90% efficient day before. On day of visit had spill, overflowed sludge tanks and first lagoon septic floating sludge.					
7	Activated sludge	800-2500	1700	10-50	13	93.8	99.3
		(floating sludge - excluded from BOD of effluent)					
8	Act. sludge and to city and plant (allowed 800 lb/day)	2200-8000	3800	400-1500	1000	25.0	73.7
		Out of control-averaging 2000 pound BOD in city/day (since going to 5-day wk)					
42	Aeration tower and act. sludge	1074-3515	2247	--	98	--	95.6
11	City Act. sludge	--	3700	60-235	145	93.7	96.1
18	City Act. sludge	--	2863	--	266	--	90.3
23	City Act. sludge	2000-5400	3700	60-235	145	88.3	96.1
45	City Act. sludge aerated (60% BOD from dairy)	740-3440	1450	--	319	--	75

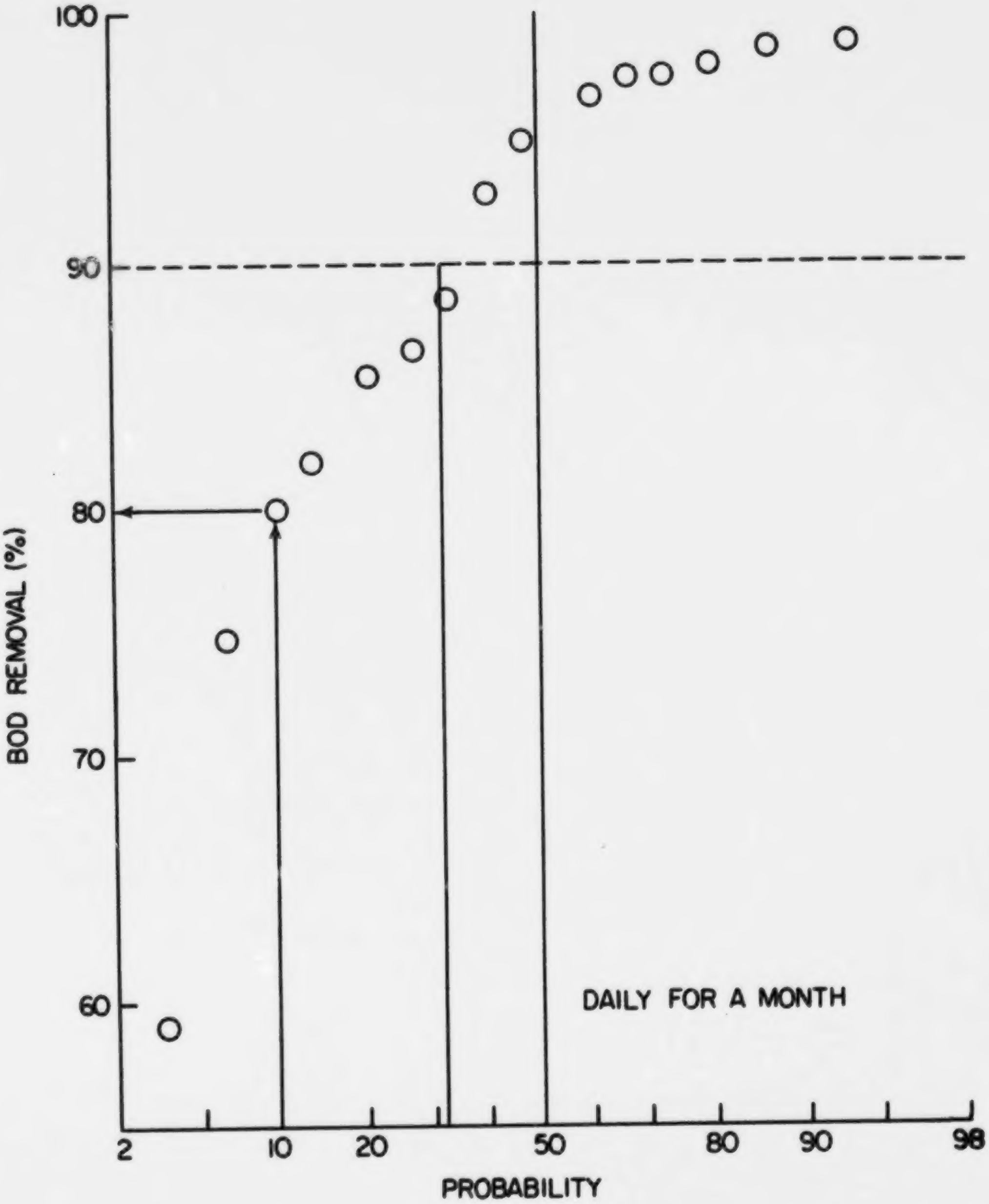


Figure 42 - BOD removal probability for activated-sludge treatment of dairy wastes (Plant 8)

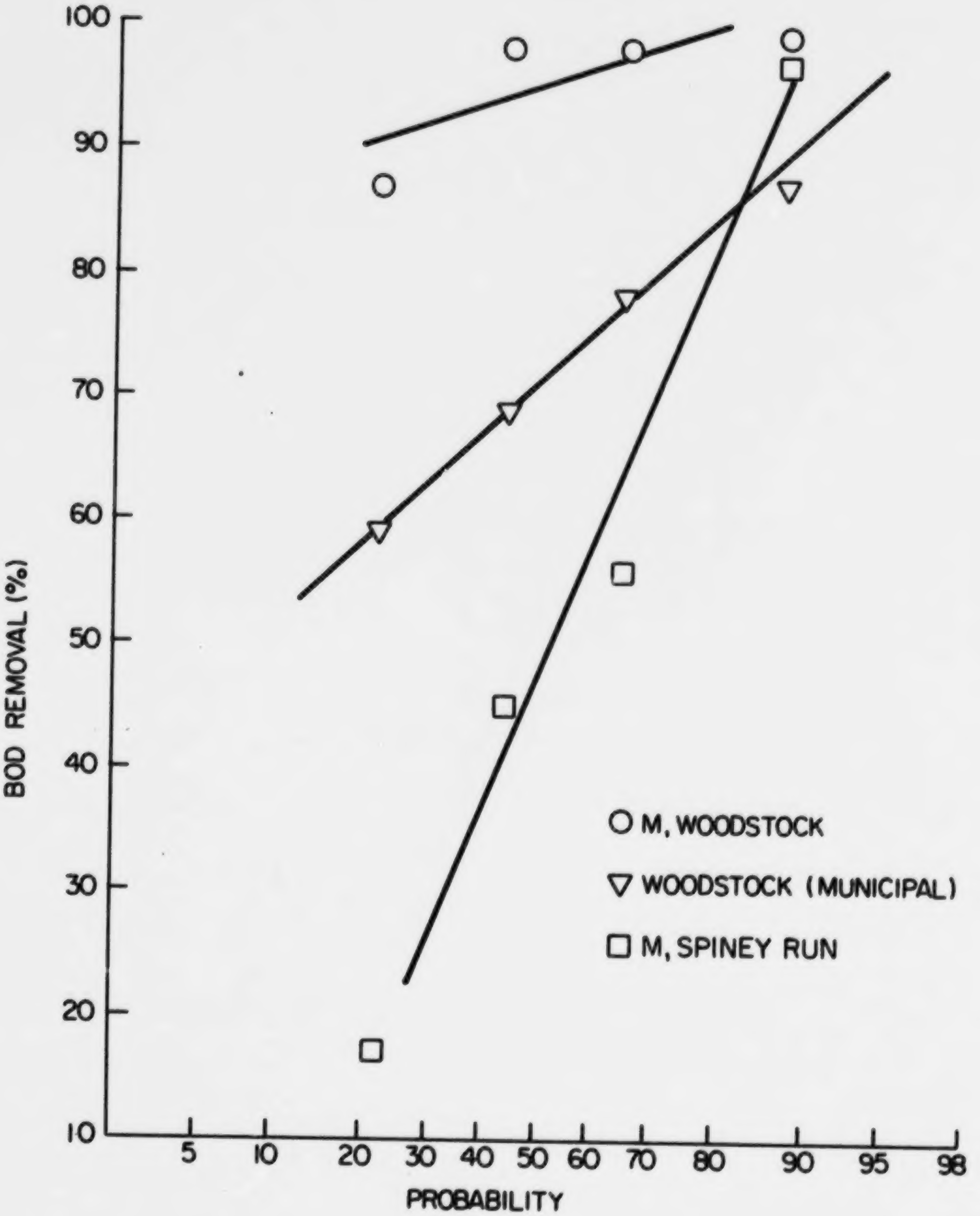


Figure 43 - BOD removal probability for activated-sludge treatment of dairy or dairy and municipal wastes after data from Pipes (815a)

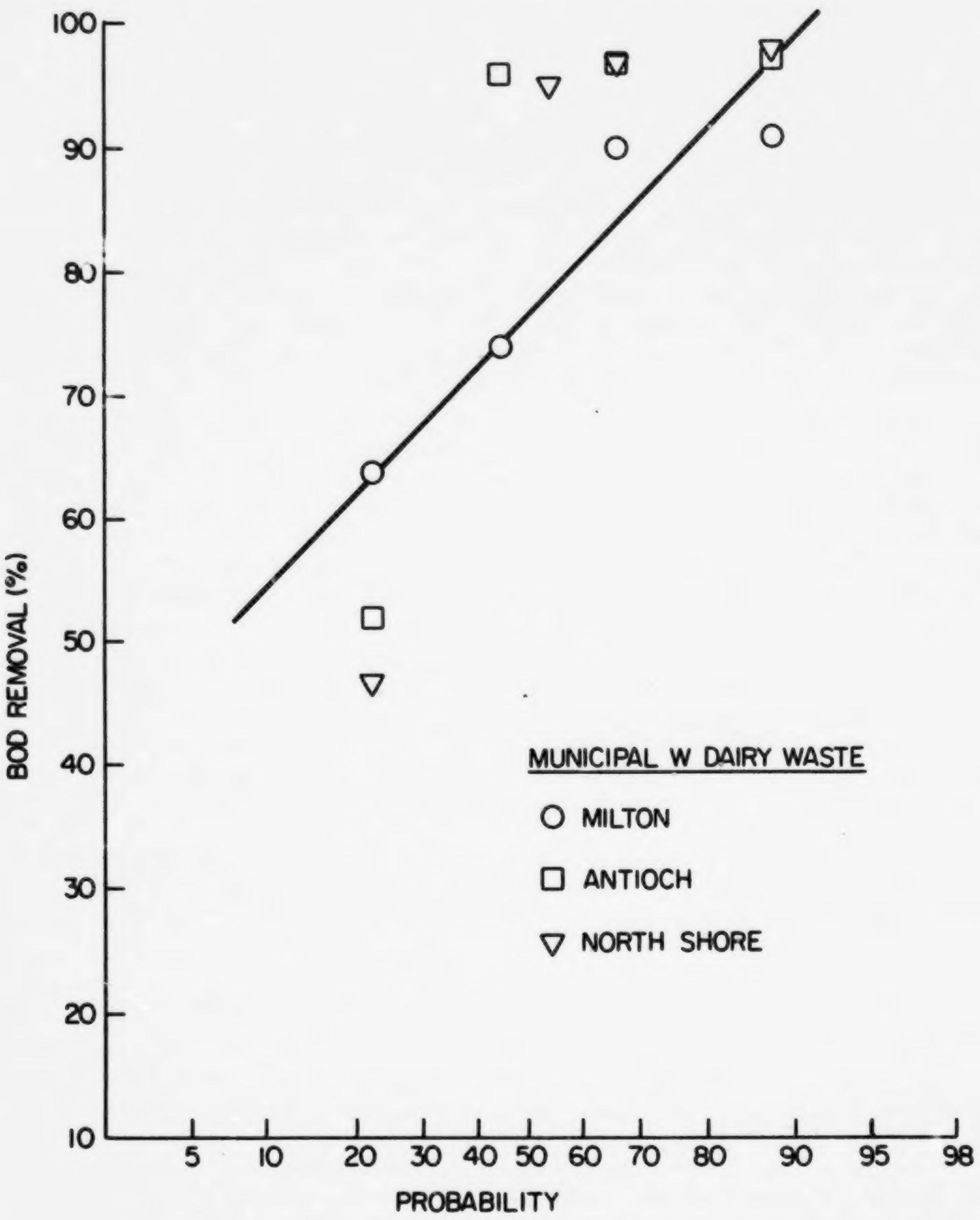


Figure 44 - BOD removal probability for activated-sludge treatment of dairy and municipal wastes after data from Pipes (815a)

removal performance to retention period in the aeration unit suggests that flow equalization is particularly important. Further, we know that the flow variation in the plants included in the industrial survey was five- to perhaps ten-fold.

The data in the tabulation of industrial and literature experiences indicates about a ten-fold variation in the air that is conventionally supplied to various processing plants. This variation appears associated with the basic transfer efficiency of the transfer device and the susceptibility of the transfer device to α-, and undoubtedly is influenced by the sludge concentrations as well as the waste characteristics. The poorer performance in respect to air requirements are indicated for studies as reported in references 1109 and 440, as contrasted to the study by Schultz (961). The former uses waste sensitive diffuser tubes, and the later studies use insensitive turbine-draft tube aeration. Most systems seem to use ejectors which are sensitive to surface active materials. Such data and C_s information are not available.

The ASCE manual (14a) of standard practice by comparison reports air usage of about 500-700 cubic feet per pound of BOD as long as loading was not less than 30 pounds per day per 100 pounds of sludge, but at lower BOD: solids ratios the average requirements for air increased enormously approaching 1200 to 1800 cubic feet per pound of BOD removed. These data were for diffused air plants. Air capacities of 150, perhaps as much as 200%, were said to be warranted in some instances in order to have stand-by capacity.

Most systems appear to operate with aeration periods on the order of 15-30 hours. Rarely is there sufficient information to assess the treatment kinetics in the processing system as contrasted to that reported by Hoover, Porges, and associates (473, 475, 476, 843) Heukelekian and Gellman (392) or Gain (314). (See Table 66) Such data should be a starting point for the design of dairy waste treatment systems.

The oxygen demand will depend heavily upon the substrate removal velocity, dF/dt. Gram (408a) has estimated as 5.1 g substrate removed/g cells-day, or a maximum removal velocity of 2.48 day^{-1} from skim milk as well as K_5 of 100 ppm BOD_5.

These maximum removal velocities and maximum loadings suggested by Gane (314) appear to be in general agreement with the kinetic data reported by the other investigators in Tables 65 and 66. Pearson (796a) suggests that this is one of the few instances of the availability of sufficient data to obtain such maximum flux and loading rates.

Quirk et al. (857a) have suggested maximum removal velocities based on sludge characteristics. When the BOD removal velocity (dF/dt) can be represented by the ratio $L_{removed}/X\theta$, the low removal velocities recommended by Quirk et al. (857a) can be achieved at loadings of less than 0.125 for the frequently used 30-hour aeration period. For dairy wastes of 1000, 1500 or 2500 ppm BOD this suggests sludge concentrations of more than 1250, 1850, and 3100 ppm, respectively. Should bulking or other sludge settling defects yielding SVI of 200 or above occur due to accidental overloads, operation at the higher sludge concentrations would be marginal and recovery difficult (351).

Articles by Horton and Trebler (479-81), Schultze (962), Trebler and Harding (1138), Porges et al. (469, 833, 826, 834b) and Mishukor (710) indicate the approaches which were current at the time these systems were designed.

In 1957 Porges modifies earlier design recommendations by suggesting that sludge oxidation may vary from 10-20% per day rather than 24% per day as suggested earlier. He further suggests that the oxygen required for the assimilation period is three hours for a 1:1 COD sludge ratio and six hours for a 2:1 sludge ratio. Previously, (476), they had implied a six-hour oxidation period in calculating the oxygen requirements as if all the wastes were assimilated within one hour. Here the assimilation load is spread out over the assimilation period.

Trebler and Harding (1138) maintained that the experimental results of Porges, Jasewicz and Hoover in 1955 indicated that the actual oxygen requirements for treatment of skim milk wastes are substantially below those reported by Kountz in 1954 and Porges, Jasewicz and Hoover in applied microbiology in 1953. (They concluded from the data that, during the initial phase, about 18% of the COD appeared as new cell protoplasm, 60% of the COD appeared as storage of a sludge and only 11% of the added COD was actually oxidized. During the subsequent storage of this same waste, a portion of the COD was oxidized and a portion appeared in the form of new cells but these processes occurred at a slow rate and yielded only 41% of COD as new cells at the end of 20 hours with 20% of the COD still remaining in storage.) They further maintained that practical experience of many workers in the field indicated that satisfactory performance may be obtained if the oxygen is provided at a more or less uniform rate, although the raw waste is known to enter with extreme nonuniformity.

Schultz (962) reported BOD removal efficiencies of 90-98.1% with air supplies from 208 to 775 cubic feet per pound of BOD, respectively. The detention period was a little over 15 hours followed by slightly less than three hours settling. Sludge was not returned continuously. The author suggested an air supply of about 400 cubic feet per pound of BOD as being necessary for 95-96% removal. He also reports that there was no problems with foaming or clogging. Aeration efficiencies were not reported. (Kinetic data based on this study are presented in Table 65).

Thayer (1109) has made some recommendations for the design of activated sludge waste treatment plants for dairies based on performance of plants near Germantown and Dayton, Ohio. These recommendations are:

(1) the waste should be separated from the uncontaminated water;

(2) whenever possible the design should be based on actual measured flow and if data are missing should be based on the assumption of 600 gallons of waste per 1000 gallons of raw milk and an estimated BOD concentration of 600 parts per million. (This corresponds to a waste volume concentration of 5.0 pounds of water per pound of raw milk received and a BOD coefficient of 3 pounds of BOD per 1000 pounds of raw milk received).

(3) The holding tanks should have a capacity of 50% of the average minimum daily flow but these are not necessary for dairies that are on a continuous or a nearly continuous operation;

(4) the aeration tank should provide a 36-hour detention based on average hydrolytic load of the waste;

(5) four hours detention in the settling tank are recommended;

(6) the returned sludge capacity should be 300% of the average 24-hour flow; and

(7) the air requirements are 5000 cubic feet of air per pound of BOD in the raw sewage using "precision diffuser tubes."

Hauer (441) alluded to a preliminary report in which high efficiencies were obtained with air supplies of 0.14 to 1.0 cubic feet per minute per pound of BOD. The latter air requirement was for jet aeration such as those used at Chemung and Huntley, Illinois at that time. Those commercial facilities were obtaining 75-97% reductions with air supplies of approximately 0.52 to 0.59 cubic feet per minute per pound of BOD.

Horton and Trebler (479-81) recommended an aeration period of about 30 hours in their design of a small conventional activated sludge system. They commented that this was slightly shorter than the 36 hours reported by Hoover and Porges (1952) as being necessary for the complete oxidation of skim milk wastes. They also commented that some holding times in aeration tanks in industrial systems are as long as 120 hours, even though it is known that this is much longer than is needed. At this point, in time, they believe that equilibrium could be achieved and did not intentionally remove excess sludge during the year and a half of operation for these systems. Later, Trebler and Harding (1138) commented on the involuntary discharge noted in all the plants of their experience.

Mishukov (710) recommended primary settling for three hours, and aeration at 1083 cubic feet per minute per 1000 cubic feet (with perforated tubes 1.5 feet below the water surface to give an oxidated capacity of 75 pounds per 1000 cubic feet for the aeration tanks). Treated effluent showed effluent BOD's of 20-25, suspended solids of 30-50, and nitrate concentrations of 10-20 parts per million.

Operational Problems of Activated Sludge Systems

Fisher (363) has concluded from his literature survey and experience that early activated sludge plants had four major operational problems:

(1) The sludge tended to bulk (or have other defects) leading to discharge of organic solids in the effluent;

(2) sludge disposal was difficult;

(3) maintenance of adequate air supplies was difficult because of clogging of diffusers; and

(4) plants required more day-to-day attention than other available means of treatment.

To these problems, we would add:

(5) Stable foams may form, often in the presence of whey or wash water;

(6) system recovery following a two- or three-day down time is poor;

(7) performance periodically may deteriorate for unexplained reasons and treatment recovery may be poor;

(8) whey discharge to the treatment plant, even at the strength of whey wash water appears to lead to operational problems and poor efficiences.

Close supervision should significantly reduce the magnitude of problems with clogging, accidental discharges, and poor sludge characteristics. Industrial experience indicates that particular attention should be given to the elimination of whey discharged as whey, or whey wash water, acid whey, in particular, and ice cream mix or other materials which have a possible imbalance in nutrient availability.

The starting point in an activated sludge treatment design or system improvement appears to be the development of positive management philosophy with respect to:

(1) The conservation and re-use of ingredients, as food-grade secondary products preferably and feed-grade secondary products when necessary.

(2) Process management responsibility for all materials used and discharged at the department level.

(3) Continuous sampling of waste volumes and composition with competent laboratory personnel.

(4) Trained and supervised treatment plant operators.

(5) A materials conservation program including familiarization with their waste treatment system, its problems, and the costs of foods diverted from the customer to sewer.

Most of these attitudes and nearly all of the routine information required for successful food processing-waste treating systems generally were absent in our industrial contacts.

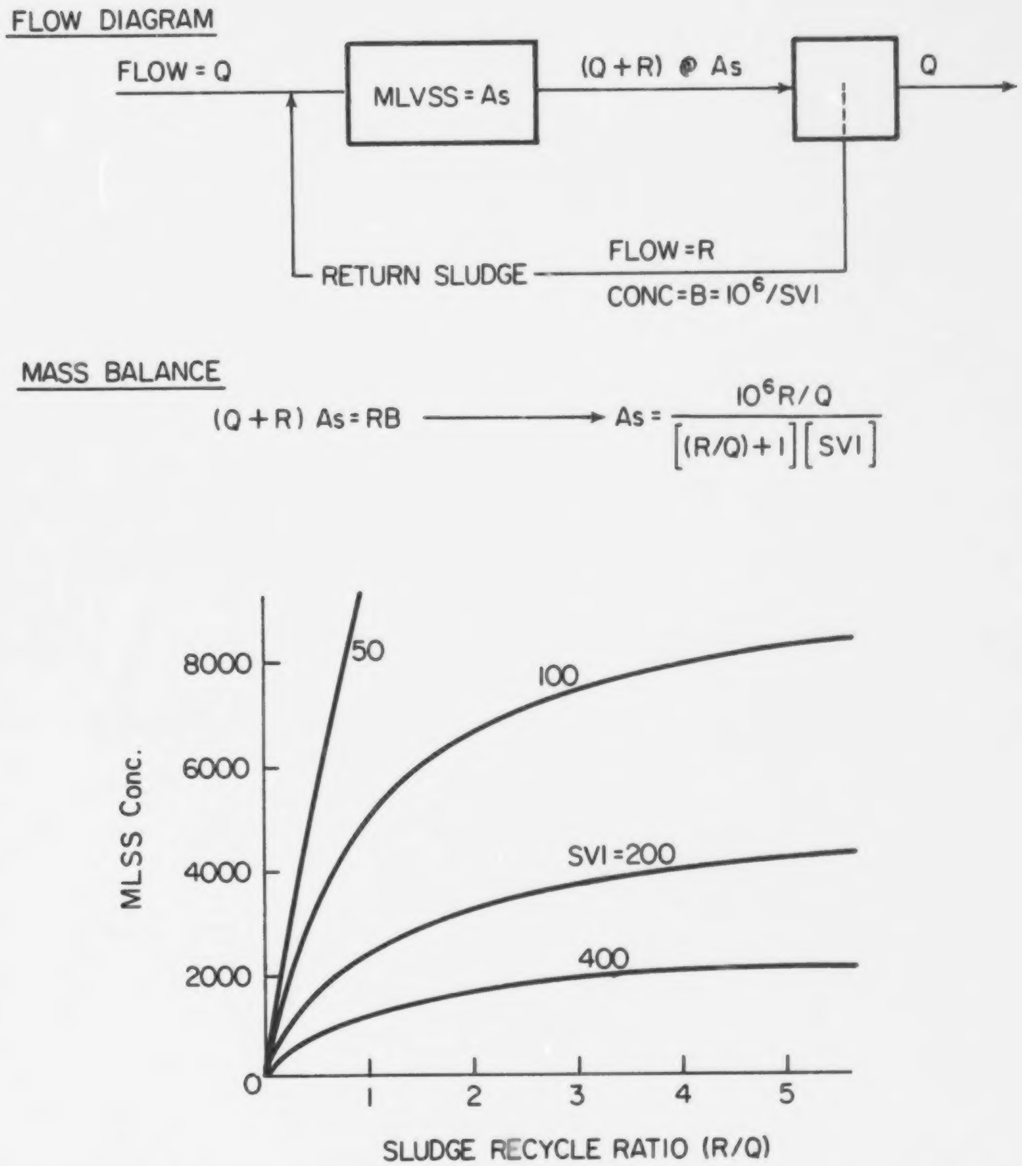
Suggestions for materials conservation and reports of industrial contacts are treated in depth elsewhere in this report.

Performance data in Tables 77-79 indicate to us a much greater likelihood of performance efficiencies of 90 percent and above on a regular basis when influent concentrations are in the order of 800-1200 ppm. Further, plants being successfully operated appear to have consciously reduced the variability of hydraulic and BOD loadings as well as their magnitude.

BOD concentrations of this magnitude make it possible to manage the BOD day sludge ratio in spite of the likelihood of ocasional bulking. Such bulking makes maintenance of high MLVSS levels difficult or impossible (see Figure 45) even at high sludge return ratios. When high sludge levels are required to maintain low BOD_5/day, sludge ratios, and reasonable system performance, successful operation during and recovery after high loads, becomes difficult. (See Fig. 45).

A number of investigators have suggested the use of a holding tank containing perhaps half the daily waste of volume. This tank provides a means of leveling out the hydraulic load, BOD load and possible inhibitor concentrations in the effluent. Such a tank also provides the opportunity to feed the sludge at a low but adequate level during two- or three-day plant shut downs. This tank would require aeration because wheys containing lactose quickly become septic.

Sludge defects such as bulking, and pinpoint floc appear to be major operational problems for a dairy plant. Fragmentary evidence and industrial impressions indicate that an imbalance of lactose availability may make these problems more severe for dairy effluents than many other industrial wastes.



$$(Q+R)\,As = RB \longrightarrow As = \frac{10^6 R/Q}{\left[(R/Q)+1\right]\left[SVI\right]}$$

Figure 45 - The influence of the sludge volume index, and the sludge recycle ratio, R/Q, upon the MLSS concentration available in the aeration basin, after Stewart (1058a)

Adamse (6) has suggested that bulking could be controlled by the addition of organic carbon that would be absorbed slowly or by sources of nitrogen that would be absorbed quickly. The second has been frequently tried with variable success. Either materials would add a significant expense to the treatment method.

An alternate, and to us a promising approach, is the management of the sludge loading. The data for references 108, 194, 262, 678, 1114, in Table 77, suggest that systems operating with BOD loads of the order of 20 pounds per 1000 cubic feet can be successfully operated to achieve 90 and above treatment efficiencies. (In one instance, the treatment efficiencies were lower but the effluent was from a cheese plant and no settling was employed.) The survey gives some fragmentary evidence of successful loading at substantially low levels as in references 438, and 752. There is also some suggestion of satisfactory performance at substantially higher loadings on the order of 1 to 400 pounds BOD per 1000 cubic feet for references 961 and 1114.

The first loading level is that encountered in activated sludge systems using the conventional, tapered aeration, step aeration or mixed tank process approaches. The second loading level is that for extended aeration, particularly the oxidation ditch, the third loading level is like that encountered in the supra-activation design approaches.

Some of these and other flow sheets available to the design engineer are shown in Figure 46. These processes along with suggested loading factors of pound BOD per day per 1000 cubic feet and pound BOD per day, pound MLVSS, and expected BOD removal efficiencies for municipal wastes as suggested by Stewart (1058a) are shown in Table 80.

Table 80 - Activated Sludge Processes, Typical Loadings and Efficiencies (after Stewart (1058a))

Name Of Process	Loading Factor (Lb BOD/Day) (1000 ft^3)	Lb BOD_5 Day/Pound MLVSS	BOD Removal Efficiency,
Extended Aeration	20	- .05- .2	75-85
Conv. Activated Sludge	35	- .2 - .5	95+
Tapered Aeration	35	.2 - .5	95+
Step Aeration	50+	.2 - .5	90-95
Activated Aeration	50+	-	80-85
Contact Stabilization	70	.2 - .5	85-90
Hatfield Process	70+	-	85-90
Kraus Process	100	-	85-90
High Rate	100	2. - 5.	60-75
Modified Aeration	100	2. - 5.	60-75
Rapid Bloc	150+	3.5 - 5.	90-95
Supra Activation	400		55-65

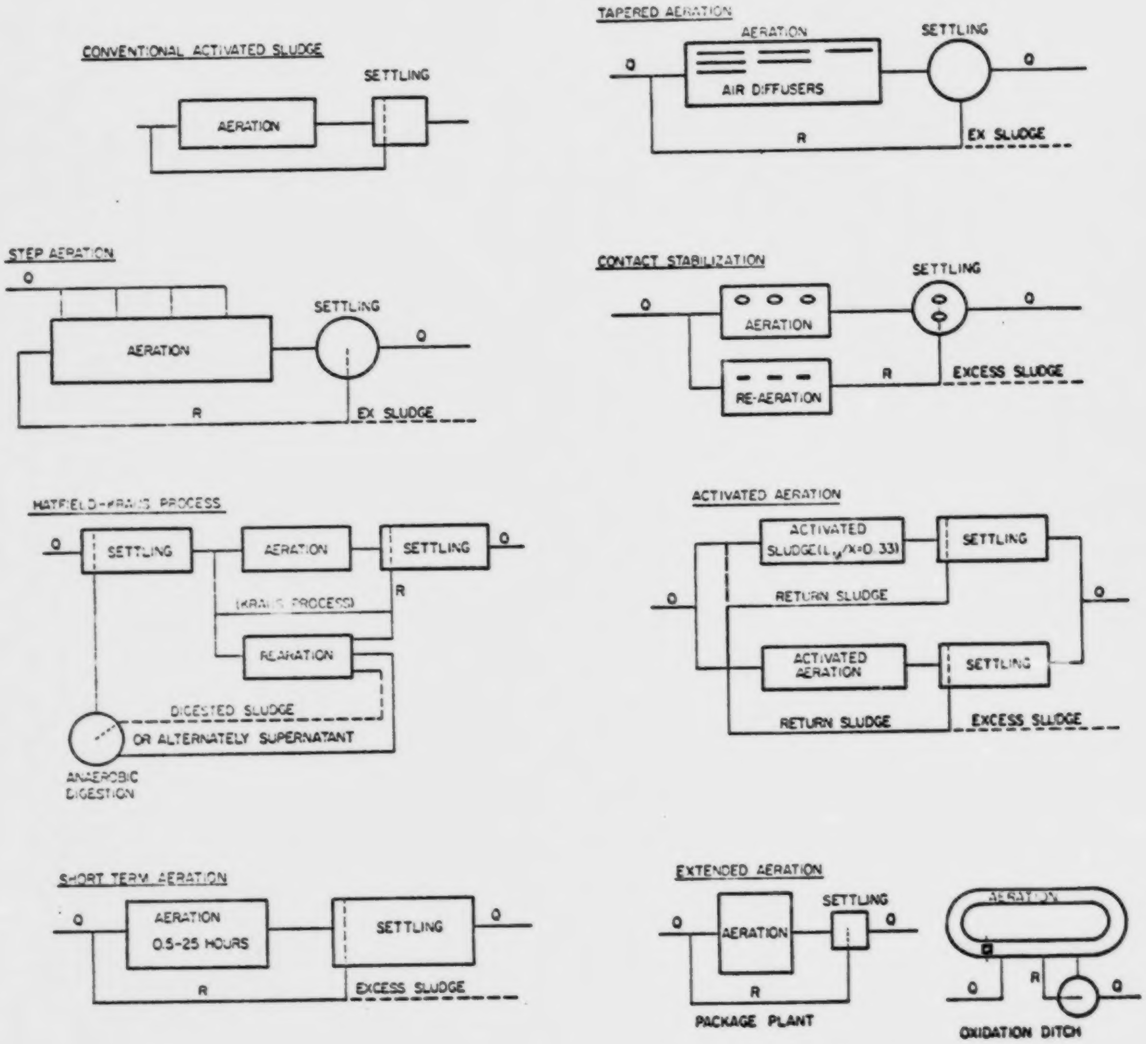

CONVENTIONAL ACTIVATED SLUDGE
AERATION
SETTLING
TAPERED AERATION
AERATION
AIR DIFFUSERS
SETTLING
Q
R
EX SLUDGE
STEP AERATION
Q
AERATION
SETTLING
R
EX SLUDGE
CONTACT STABILIZATION
AERATION
RE-AERATION
SETTLING
EXCESS SLUDGE
HATFIELD-KRAUS PROCESS
SETTLING
AERATION
SETTLING
(KRAUS PROCESS)
REAERATION
DIGESTED SLUDGE
OR ALTERNATELY SUPERNATANT
ANAEROBIC DIGESTION
ACTIVATED AERATION
ACTIVATED SLUDGE
SETTLING
RETURN SLUDGE
ACTIVATED AERATION
RETURN SLUDGE
EXCESS SLUDGE
SHORT TERM AERATION
AERATION 0.5-25 HOURS
SETTLING
EXCESS SLUDGE
EXTENDED AERATION
AERATION
SETTLING
PACKAGE PLANT
AERATION
OXIDATION DITCH

Figure 46 - Activated sludge process flow diagrams, after Stewart (1058a)

These design approaches attempt to avoid the region of loading in which Quirk et al. (857a) report problems of severe bulking with whey-dairy-municipal wastes. (See Figs. 47 and 48). The sketch shown in Figure 49 taken from Stewart (1058a) shows the type of bulking versus loading behavior he expected from municipal wastes. Stewart also suggests that pinpoint floc might well be expected at still lower loading rates, such as the oxidation ditch. Adamse has reported pinpoint floc in such a system, and the data of Pipes (815a), with respect to loading versus these defects, are not conclusive.

Stewart also suggest in Figure 49 that higher loadings will give poor treatment efficiencies but he attributes this to the high BOD in the clarified effluent and diffuse sludge that unintentionally appears in the effluent. This efficiency can be significantly improved by staging the high loading level systems as has been practices by Schulze for cheese plant wastes (961) and has been tried for municipal wastes by the Union Carbide research group (9c).

The tapered aeration, step aeration, and well-mixed tank or highly-agitated, highly-loaded, well-mixed tank avoid the possibility of extremely low dissolved oxygen levels in the contact region. Such low levels of oxygen at periods of high lactose versus protein loading may contribute to the increased storage or decreased utilization of wastes in a form which may become complexed with incoming wastes in other cells. These design approaches, which distribute the incoming load over the entire sludge mass, appear to have potential or reduce the susceptibility to shock loadings. Recycle ratios of the magnitude used in high rate trickling filters to reduce shock sensitivity must be weighed against the potential reduced sludge activity expected for high sludge ages in dairy systems.

Intentional sludge wastage appears desirable. Pipes (815a) has noted bulking in systems, even those at low loading, when there was no intentional sludge discharge. Siddiqui (1007) has reported lack of enzyme activity upon prolonged aeration of sludge with low substrate availability. Wuhrmann (1278) has reported a significant decrease in the activity of sludges for lactate upon extended aeration, also at low substrate availability.

An approach is the aerobic digestion. The data of Quirk indicate that this digestion would be relatively slow. The data of Kountz (505) indicate that endogenous respiration rates as low as 2.3% per day may be encountered. The data of Boon (181-2) indicate significant reduction in filterability of these wastes upon extended aeration. If extended aeration is used, it appears that some means of sludge separation may be required, such as flotation or centrifugation and the effluent will need to be further polished in a two-stage lagoon system.

Pien (807-10, 814) has followed the aeration treatment with anaerobic digestion of the sludge. He and investigators in Czecholsovakia

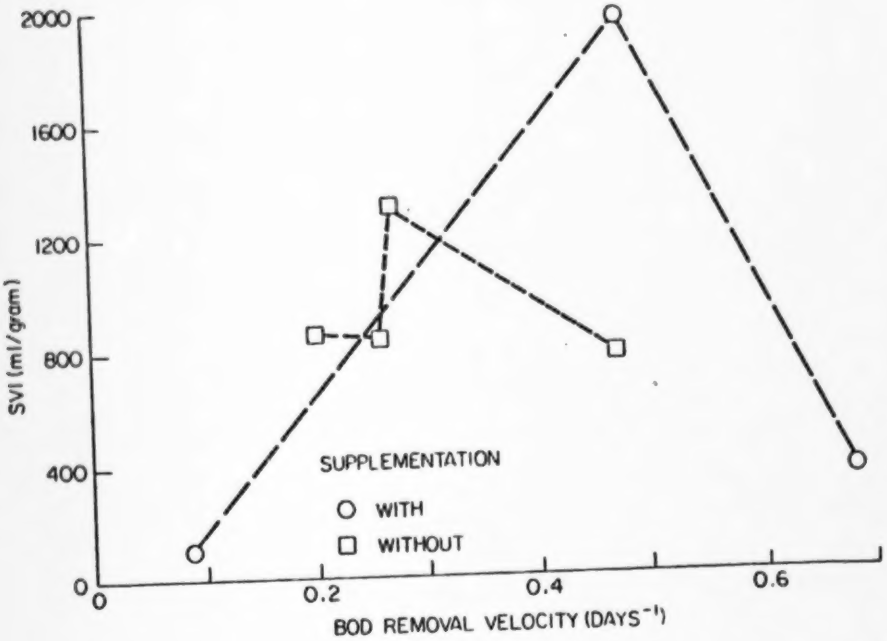


Figure 47 - Influence of BOD removal velocity, day^{-1} upon sludge volume index, mℓ/gram (857a)

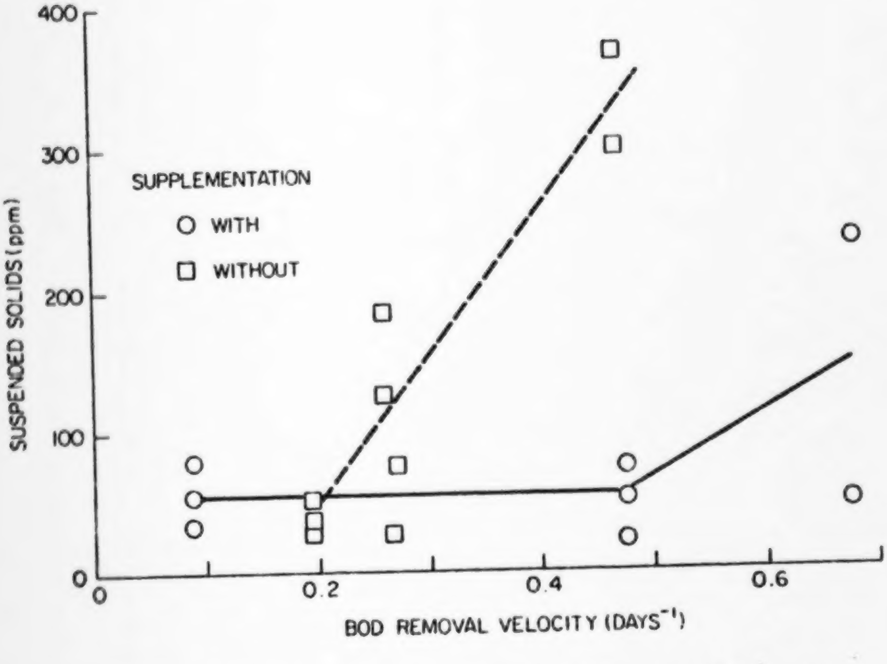


Figure 48 - Influence of BOD removal velocity, day^{-1} upon sludge volume index, mℓ/gram (857a)

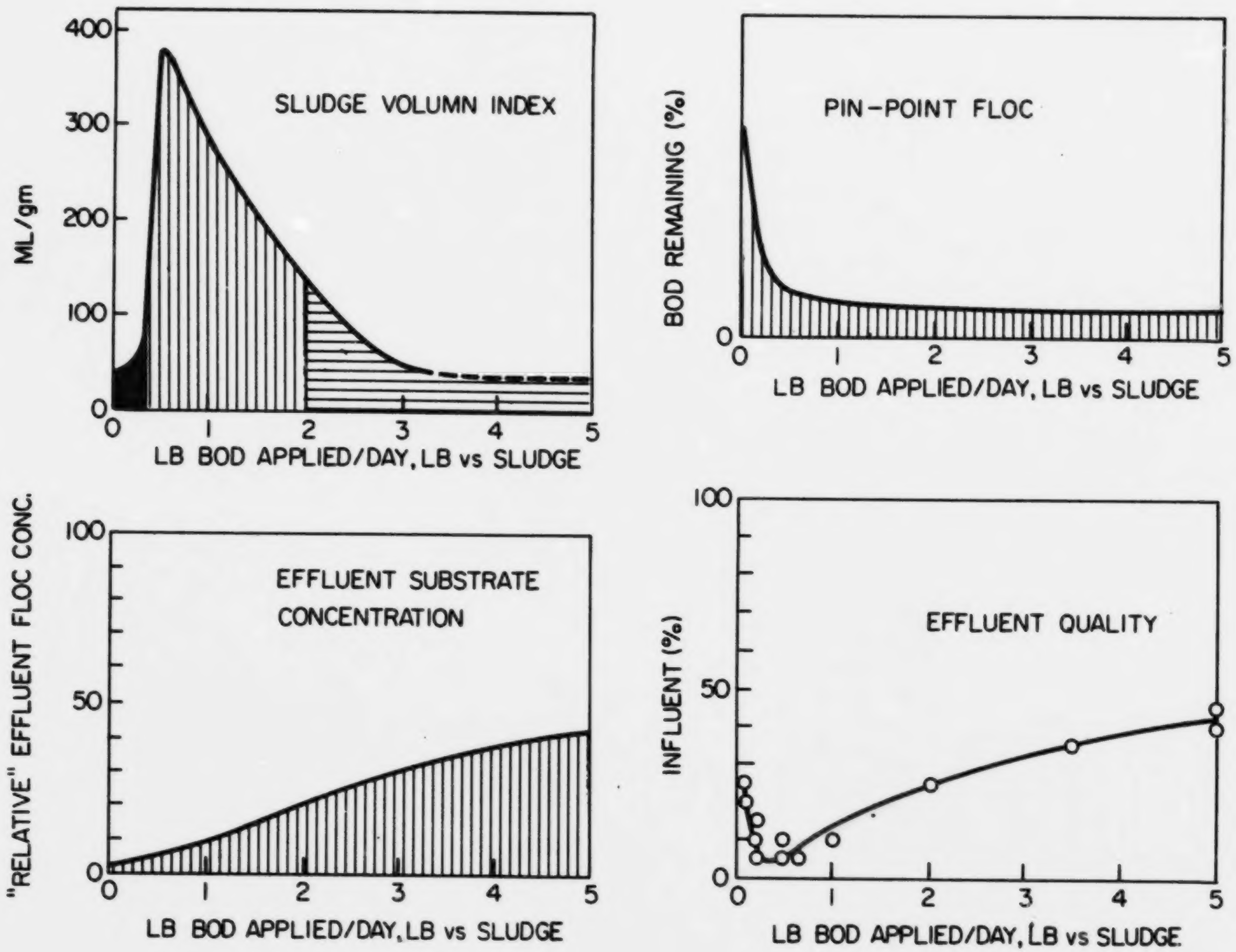


Figure 49 - Suggested sludge volume index, pinpoint floc formation, effluent substrate, and overall effluent BOD dependence upon loading factor, pound BOD applied per day, pound MLVS (after Stewart (1058a))

(1085) have reported some success with this method. There appears to be little first hand experience with this approach in the United States.

Alternate approaches for sludge disposal include centrifugation and/or filtration. The data of Boon indicate that filtration specific resistances are not prohibitive when sludge is not aerated for extended periods. An unpublished study alluded to by Quirk (857b) indicates some potential problems in this approach. It appears that sludge disposal remains a significant problem to be answered.

System design should not be undertaken without lab-scale or pilot plant confirmation in the intended loading and process region of operation. Particular attention needs to be given to the problem of loading versus sludge defects and these studies need to be continued for sufficient lengths of time to assure the acclimatization periods of several weeks reported by Adamse.

BIOLOGICAL FILTRATION

There appears to be two basic approaches to the application of biological filtration to the treatment of dairy waste waters. In the United Kingdom, the alternating double filtration approach was instituted by the Department of Scientific and Industrial Research in 1941 as a means of extending treatment capacities at a period of high stress. In the U. S., the primary method of utilization of biological filtration is the high rate recirculating trickling filter. More recently, the use of a rotating disc as a means of carrying the biological film, and as a means of aeration, has been suggested. There has also been the recent substitution of plastic media to replace the slag clinkers or stones more commonly used.

The design critieria for the alternating double filtration approach was outlined in 1967 by Wheatland (1239). Industrial experiences with this design have been reported by Rumpt (909), Divet (301) and Silvester (1014).

In the United States, the high rate recirculating trickling filter has been used infrequently in comparison with activated sludge units. This process has been applied in single and in double stages. It has also been applied as a second-stage treatment following aeration, anaerobic digestion, or chemical coagulation by either alumino-ferric chloride salts. Design experiences with single-stage filtration have been reported by Gloyna (402), Woolings (1272), Morgan and Baumann (729), and Saldaka (1016).

Design experiences with two-stage systems have been reported by Trebler and Harding (1135), Morgan and Baumann (729), and Klein (567). There has been an application of the two-stage filtration system to treatment of whey by Ingram (502) in 1961.

Trebler and Harding (1135) also report experiences with the use of the trickling filter as a second-stage treatment following aeration. Svoboda et al. (1091) in 1964 reports experiences with trickling filters to treat sludge produced by anaerobic digestion. Southgate (1035a) and Walzholz et al. (1211) have reported the use of trickling filters following treatment of waste by coagulative salts.

BOD Removal Relationships

Expressions for the removal of BOD by biological films have been developed in a manner similar to the developments for BOD removal by activated sludge. Basically the approach is to start with a material balance on a portion of the biological treatment unit, then to substitute a kinetic relationship, which has been shown to describe the BOD removal as a function of time, biological solids and waste concentration.

Let us follow the approach of Quirk et al. (857b) and first consider a vertical plate and then extend the analysis to a packed column such as found in trickling filters.

The materials balance expression is shown verbally in equation [26] below.

$$\text{INPUT} - \text{OUTPUT} - \text{REMOVAL} = \text{ACCUMULATION} \qquad [26]$$

When the treatment unit is operated with steady loading, the accumulation term may be neglected. For a small volume of the biological treatment unit, the materials balance can be expressed as shown in equation [27].

$$(Q + R)dL = K_r \, dV_r \qquad [27]$$

where

Q = flow rate of untreated waste
R = flow rate of recycled waste
dL = waste concentration change
K_r = waste removal rate,

and

dV_r = small element of the reactor volume.

The reactor volume may be re-expressed in terms of a small element of reactor height as shown in equation [28].

$$dV_r = WxdH \qquad [28]$$

where

W = width
x = thickness of waste layer
dH = small element of reactor height

When equations [27] and [28] are combined the rate of removal of waste per unit reactor height may be expressed as shown in equation [29]

$$\frac{dL}{dH} = K_r \times \left[\frac{W}{WTR}\right] = \frac{K_r\ x}{U'} \qquad [29]$$

where (Q + R)/W may be considered to be the unit hydraulic loading on a unit width of plane, U'.

$$\frac{L_e}{L_o} = e^{-K_n \times H/U'} \qquad [30]$$

Here, the BOD removal relationship has been expressed in terms of the hydraulic load on a unit width of plate in a specified time, U'. In practice, however, the unit loading rate is influenced by the surface area available per unit volume, the fraction of surface area of the packing material wetted, and the fraction of the wetted area which is actually occupied by the surface of biological mass. Further industrial experience with packed bed absorbers in the chemical industry, as well as with biological film treatment units, indicates that U' values are influenced by the application rate. Some empirical expressions for correcting for these factors are shown in equations [31], [32], and [33].

$$U' = UA_vC_wC_t \qquad [31]$$

where

U = application rate to unit tower area, e.g., gpm/ft^2
A_v = manufacturers rating of media surface area/unit volume, ft^2/ft^3
C_w = fraction of surface area wetted by the packing media
C_t = fraction of wetted area occupied by surface of biological mass

$$C_w = C_1U^n \qquad [32]$$

where C_1 and n are experimental constants,

$$(K_r)_{bed}/(K_r)_{plate} = C_2U^n \qquad [33]$$

where C_2 is another experimental constant.

Often the first order expression for BOD removal rate is utilized with the above equations. Thus the BOD removal velocity, K_r, can be expressed as shown in equation [34].

$$K_r = k\ X\ L \qquad [34]$$

where

k = rate constant, e.g., $ppm^{-1}min^{-1}$
X = effective concentration of biomass, e.g., ppm
L = waste concentration at a point.

In this equation the effective concentration of the biomass is often approximated as shown in equation [35]. When this relationship is substituted into equation [34] the factor C_B for the weight of biomass per unit area is often incorporated into the rate constant, k, to form a new constant, k'.

$$X = C_B/X \qquad [35]$$

where

C_B = weight of biomass/unit area
X = thickness of liquid layer.

The influence of temperature on the reaction rate, k', is usually expressed in the same form as that reported for activated sludge systems. This relationship may be expressed as shown in equation [36].

$$k' = k'_{20}\Theta^{\Delta T} \qquad [36]$$

where

k = reaction rate at temperature T
k_{20} = reaction rate at 20°C
ΔT = temperature (T-20)°C
Θ = an experimental constant. (See Table 67)

Often a portion of the waste from the treatment unit is recycled to combine with the raw waste. Since the treatment unit responds to the loading applied to it, this does influence the efficiency of the unit as shown in equation [37]. Here the efficiency is reported as the BOD removed from the raw waste leaving the treatments unit divided by the BOD of the incoming raw waste.

$$\frac{L_o}{L_e} = \frac{1+r\ (1-E)}{(1+r)\ (1-E)} = f \qquad [37]$$

where

r = recycle ration, R/Q
E = efficiency
L_o = waste concentration supplied to the biological film
L_e = waste concentration leasing the biological film

When these relationships are combined the overall expressions for the fraction of BOD removal for plates or packed beds may be expressed as shown in equations [38] and [39].

$$f = e^{k'_{20}\Theta^{\Delta T}H/U'} \quad \text{for inclined planes} \qquad [38]$$

$$f = e^{k'_{20}A_vC_wC_t)^{h}C[\Theta^{\Delta T}H/U^{n}]} \quad \text{for packed towers} \qquad [39]$$

Similar expressions for the BOD removal may be developed from the kinetic equation forms used for activated sludge, but with an expression relating the mean detention time to the flow characteristics and the specific surface area. Howland (482a) has shown that the mean detention time is proportional to the filter depth and inversely proportional to a power of the hydraulic loading. Eckenfelder and Barnhart (314c) have shown that this mean retention time is significantly increased by the presence of slime on a previously unslimed surface and is influenced by the specific surface area available to the fluid. A combined expression for the detention time is shown in equation [40].

$$t = C_3\,\frac{HA_v^{\ m}}{Q^p} \qquad [40]$$

Experimental Values for Rate Constants

Quirk et al. (857b) have made an extensive study of the kinetics of a synthetic "whey" waste, supplemented and unsupplemented, and of other fractions of a municipal waste.

The synthetic whey waste used in these studies was prepared from 1.55% whey, 0.09% skim milk, 15.9% settled sewage, with the remaining 82.4% being tap water.

For their inclined plane, the exponent, n, on the unit loading, U, was found to be 1.0. They also report that the overall correction factor, C, in equation [39] was one for their system. They report their results as k'_T, gpm/ft^2, or as an overall coefficient K_T, gpm/ft^3.

The kinetic data reported by Quirk et al. (857) for their inclined plate systems are shown in Table 81. These values of k'_T are not significantly different than that shown by Quirk et al. for the experiments of Schulze (964a,b, 967) for his whey and sewage on vertical screens.

Table 81 - Rate Constants for Trickling Filtration of Whey-Sewage Containing Wastes (after Quirk et al. (857b))

Added Nutrients	T, ^oC	pH	Recycle	k'_T gpm/ft^2	Fig.
Fe*	20	7.0	-	0.0013	10
None	20	7.0	-	0.00115	10
N,F	20	7.0	-	0.0016	11
N^2**	20	7.0	-	0.0016	11
N,F	20	-	0	0.00175	12
-	20	-	0	0.0017	13
-	20	-	2-3	0.0020	13
N,F	20	4.5-4.8	-	0.0028	14
N,F	20	7.0	-	0.0016	Also
N,F	20	9.8	-	0.0011	p4.10
N,F	22-24	-	0	0.0019	16
N,F	25-27	-	0	0.0018	15
N,F	29	-	0	0.0022	15
N,F	30	7.0	-	0.0016	16

*1.5 $MgFe^{++}$ per liter
**37.5 mg/ℓ.

From this data they concluded that ferrous ion was shown to be of no demonstrable value in increasing the rate of BOD removal, but significant increases could be achieved by the addition of nitrogen. They recommended the nitrogen addition in process design.

The data further indicate that the apparent reaction order constant, k, was not significantly influenced by BOD concentrations in the range of 200 to 600 ppm. Recirculation was not found to significantly influence the apparent rate constant. However, pH changes in the range of 4.5 to 9.8 did produce significant changes in the rate constant. They concluded that the data for the several different temperatures follow the temperature model shown in equation [40] and that the value of θ has been verified to be 1.035 as previously reported (312a), (see Table 67).

Later they concluded that the k'_{20} weight constant for whey is 1.6×10^{-3} gpm/ft^2.

When this value of the rate constant is combined with reported values of 27 ft^2/ft^3 for the packing material, A_V, an available surface coefficient C_t of 0.8 and a wetting coefficient $C_W = 0.90$, the overall rate constant K_T is reported to be 0.03 gpm/ft^3. K-values for this and other wastes are shown in Table 82.

Table 82 - Comparison of BOD Removal Rate Constants for Trickling Filtration of "Whey" With Those for Other Wastes (after Quirk et al. (857b)

Effluent Origin	K-gpm/ft^3
Integrated Kraft Mill	0.018 to 0.044
Ragmill	0.083
Boxboard Mill	0.027
Canning Waste	0.021
Slaughter House Waste	0.044
"Whey"	0.030

$$K_T = k'_T A_V C_t C_W \qquad [41]$$

where

$A_V = 27$ ft^2/ft^3 for "Surf Pac"
$C_t = 0.8$ for whey
$C_W = 0.9$ for "Surf Pac" or similar media.

Blakrishran and Eckenfelder (142) have gathered specific surface ft^2/ft^3 values, A_W, and values of the power index, n, for other systems (and corresponding apparent rate constants for nitrification). These values are shown in Table 83. Data for the larger $2\frac{1}{2}^{+}$-$3\frac{1}{2}$ aggregates and large opening plastic media are also needed. Such larger packing openings appear to be an important factor in decreasing the incidence of ponding due to the lush growths encountered, particularly in the top region in the first of a series of filters treating whey bearing wastes.

Table 83 - Summary of Data on Nitrification in Trickling Filter (after Blakrishran and Eckenfelder (142))

Description	A_W Specific surface (ft^2/ft^3)	Temp. range (°C)	Depth (ft)	Hydraulic loading range (MGAD)	n
1 in. Raschig rings and 1 in. Berl saddles*	67	21-38	6	10-30	0.49
$1\frac{1}{2}$ in.-$2\frac{1}{2}$ in. Slag**	38	22-27	6 & 8	2-20	0.48
1-2 in. Brooksville limestone**	50		8	2-7	0.85
1-2 in. Chattahoochee River gravel**	30		6	2-7	0.93
1 in. Clinker¶	61.6	7-17	6	1-1.2	2.56
$2\frac{1}{2}$ in. Clinker¶	37.4				0.84
1 in. Slag¶	60				0.30
$2\frac{1}{2}$ in Slag¶	33				0.75
1 in. Rock¶	43.3				2.36
$2\frac{1}{2}$ in. Rock¶	27.6				3.80
1 in. Rounded gravel¶	44.5				3.00
$2\frac{1}{2}$ in. Rounded gravel¶	19.7				5.40

*Laboratory scale studies, Austin, Texas

**U.S. pilot plant studies (Grantham et al., 408c; Grantham, 408b)

¶British pilot plant studies (Wat. Pollut. Res. Lab 1959; Wat. Pollut. Res. Lab (1960)

As in activated sludge, the lactose appears to disappear first followed by the protein fractions, for Svoboda et al. (1094) found complete lactose removal but only 22-66% nitrogen removal (+20 to 44% following sedimentation) in a pilot plant study.

Behn and Monadjeni (154b) have recently reported on the developments in biological filtration. They compared the formulations of Velz (1183a); Stack (1045a); Phelps and Velz (804a); Fair and Gener (349a); Howland (482a); Sinkoff, Porges, and McDermott (1015a); Schulze (965a); Eckenfelder (311c); Ames, Behn, and Collings (14a); Amado (11a); Atkinson, Bush, and Dawkins (129a); and more recently, Galler and Gotass (382b).

In their analysis they show most equations to be of exponential form similar to that shown in this report, whether obtained from a postulation that the amount of BOD removed per unit depth was proportional to the BOD remaining, as in the early paper by Velz (804a), or starting with the proposition of Howland (482a) that the rate of BOD removal was a function of time of contact.

Subsequent modifications have included retarded reaction (311c), incorporation of an overall coefficient reflecting the two resistances of absorption and reaction (11a), or the concept of Michaelis-Menton-type kinetics (575b, 857b), and refinement of expressions for the fractional returning achieved recirculation (311c) and consideration of the residence-time distribution (154b, 575b).

While the trickling filter theory is being refined Behn and Monadjeni (154b) suggest utilization of the equation of Eckenfelder (311c) or that of Amado (11a) which show sensitivity to the hydraulic loading but do not show more than slight indirect sensitivity to BOD loading.

Sludge Yields

Quirk et al. (857b) estimated* that seven-tenths of the BOD supplied will be converted into sludge because the sludge growth should be comparable to that experienced by activated sludge. Their experimental results indicated a sludge production of 1.0 pounds of dry solids/pound BOD for trickling filter efficiencies of 75%. But, they note that low sludge yields are generally associated with high BOD removals of about 85-95% for other wastes; thus reduced their expected sludge yield of a system to produce 90-95% removal.

Sludge Characteristics: Quirk et al. also reported the results of settling tests for the whey and sewage trickling filter plane effluent. In a 30-minute settling period for waste initially containing from 42-550 ppm, an average of 160 ppm, the supernatant at 150-ml level in a 500-ml graduated cylinder ranged from 30 to 200 ppm with an average of 100 ppm, giving an average removal rate of suspended solids of 37.5.

The results of their sludge thickening studies are shown in Table 84. The experimental constants reported in this table are defined in equations

$$\frac{X_y - X_a}{X_a} = \frac{\Delta X}{S_a} = \frac{K_t}{(SL)^{N_t}} \qquad [42a, 42b]$$

---

* No other data were found in the literature for sludge yields from trickling filter systems.

where

X_a = sludge concentration applied to thickener, ppm
X_y = sludge concentration leaving in the underflow
ΔX = increase in sludge concentration achieved
K_t = thickening constant dependent on geometry and S_a
N_t = constant for a sludge type
SL = sludge loading lb/ft^2, day

Table 84 - Comparison of Sludge Thickening Characteristics (after Quirk et al. (857b)

Sludge Source	Thickener Constants N_t	K_t	Concentration Constant N_c
Sewage	1.05	150	0.088
Yeast Effluent and Sewage	1.00	350	0.270
Kraft Effluent	0.56	41	0.086
Kraft and NSSC Effluent	0.70	115	0.220
Whey Effluent from Trickling Filtration	0.57	37	0.167
Whey and Sewage from Trickling Filtration	0.80	46	0.121

The influence of sludge concentration, S_a upon K_t may be approximated by the relationship

$$K_t/K_t' = e^{-N_c(1000)X_a} \qquad [43]$$

where K'_t is the maximum value of K_t obtained for a dilute solids concentration, a thickener load of 6 pounds solids per square foot per day.

Morgan and Baumann (729), made an intensive study of two trickling filter systems for the treatment of milk wastes. In Plant A the settling rate in the final clarifier averaged about 250 gal/ft^2 - day while the generally recommended loading is about 800 gal/ft^2 - day (504a). The detention time in the clarifier averaged about 4-1/2 hours as compared to the normally adequate 1-1/2 hours (504a).

Plant B operated with a clarifier settling rate averaging 450 gal/ft^2 - day. This clarifier was reported to be more than adequate. The detention time was about 2.2 hours. The surface settling rate in the final clarifier was 1,200 gal/ft^2 - day with a detention time of about 0.7 hours. The corresponding recommended surface settling rate for a final clarifier is 800 gal/ft^2 - day and a recommended detention time is 1-1/2 hours. They suggest that the final clarifier was too small.

Plant A used a digester for disposal of sludge. The digester capacity varied between 0.5 and 1.1, and averaged about 0.7 ft^3 per capita on a BOD population equivalent basis, yet was too small for the sludge was only partially digested when it was removed. Plant B used a dry gravel pit as a source for sludge disposal. No odors or other nuisance was created.

No reports on sludge volume were given.

Wieselberger (1247) reported successful operation with surface loadings of 71 to 150 gal/ft^2 - hr.

Zack (1287) studied a trickling filter unit with dual filters and dual clarifiers followed by an unheated digester and sand beds. The digesters were sized at a rate of 3.1 to 4 ft^3 per capita unit of suspended solids. The sand drying beds which were open were sized at 1 square foot per capita.

Rugaber (905) found that utilizing the sludge drying beds batchwise without applying successive layers gave better performance.

Tribyslov (1145a) reported on continuations of their work of the performance of a high trickling rate filter. For his system, the sedimentation tank had a surface loading of 988 gal/ft^2 - day and a volume loading of 0.76 m^3/m^3 - hr for a 1.3-hour retention.

Centrifugation Tests: Quirk et al. (845b) reported solid recoveries of from 59 to over 89% with cake solids of 5.5 to 9% without chemical aids and percent recoveries of from 81 to 86 with solids concentrations of from 5.9 to 6.5 with chemical aids. They concluded that solids dewatering by centrifugation is not effective for secondary sludge and that the cost of chemical additions to improve performances are not economic.

Vacuum Filtration: Studies by Quirk et al. (857b) using vacuum filtration loading of 1.2 lb/ft^2/m-g and 7% $FeCl_3$ produce a cake of 20-25% solids. They found that the addition of lime did not increase the filtration characteristics and at times decreased the filterability. Polymer addition was reported not to ~~be~~ economical in comparison to $FeCl_3$ addition. The sludge coefficient of compressibility is reported to be 0.91.

Performance Data

Performance data for trickling filters have been extracted from direct or indirect reports available to us. These data are presented in Table 85.

Three different approaches are included in Table 85: (1) alternating double filtration, (2) low rate filtration, and (3) high rate filtration. Some characteristics of these approaches are given in Table 86.

Table 86 - Loadings and Depths of Trickling Filters
(after (350, 1238))

	Low-Rate Operation	High-Rate Operation
Hydraulic loading		
gpd per sq ft	25-100	200-1000
mgad	1.1-4.4	8.7-44
Process loading--BOD		
lb per 1000 ft^3 daily	5-25	25-300
lb per acre-ft daily	220-1,100	1,100-13,000
Depth, ft		
Single-stage	5-8	3-8
Multistage	2.5-4	1.5-4
Recirculation		0.5-10

The data of Trebler and Harding (1133), Christensen (228), Morgan and Baumann (729), and Wieselberger (1247) give some idea as to the variability in performance to be expected. In the first instance the BOD loading variability was simulated by extra milk losses. Most of the loading variability in the two other studies was normal monthly (or daily) variation.

Trebler and Harding (1133) reported their results with two-stage trickling filters in the form of a scatter diagram shown in Figure 50. The design load for this figure was 66.5 pounds of BOD per 1000 ft^3 day. An effluent concentration of 60 ppm on the average appears to correspond to an average reduction of 96.5%. (This corresponds to a influent concentration of about 1820 parts per million). The authors suggest that in some instances the reported loadings may be only half those actually applied to the system because the equalization tank ahead of the primary filter was inadequate.

The data indicate quite good performance for a trickling filter operation with an average of a little over 80% efficiency per stage. The effluent BOD levels of 17 and 120 ppm still give effluent concentrations too large for discharge to streams. In these instances the waste would need subsequent treatment.

Table 85 - Performance of Trickling Filter Treatment Systems

Product or Process	Influent MGD	BOD, ppm Influent	BOD, ppm Effluent	% BOD Removal	Hydraulic Loading MGAD	Depth, ft.	Recycle Ratio	BOD Load, lb 1000 ft³ day	Temp., °F	Remarks	Ref No.
Dairy plant	--	200-300	10	--	160*	--	Yes	--	80-90	A.D.F.	10
Dairy waste with municipal wastes	0.15	930	16-30	97-98	--	--	1.64	--	--	--	19
Dairy	--	--	--	36	--	--	--	--	70-72; 72-out	pH 8.1; 79 out; poor Mgt; TS 1050 ppm in, 940 ppm out	
Cheese plant	0.022 0.044	--	--	66	20 -30	--	--	--	--	Projected from lab data by NYU. 2½ in. gravel. 0.5 gal/ft³ depth recommended. See also Reference (502)	94
		--	--	35-40	50 60	--	--	--	--	--	94
		--	--	up to 70	70 80	--	--	--	--	--	94
Dairy	--	--	--	--	63	--	High	1670	--	Recommended tower filter 43.4 gal/day-ft³	103
Dairy plants: cream, milk conc., yogurt butter, cottage cheese	0.3	1200-1800	250-300	75-86	0.3	--	--	--	--	--	128
	0.24	800-1800	--	81-96	0.24	--	--	--	--	--	128
	0.35	1000-1200	--	70-83	0.14	--	--	--	--	--	128
Dairies	--	600	120	80	--	--	--	--	--	From Ruf & Warrek (1935)	(904a)174
	--	537	46	91	--	--	--	--	--		(330a)174
	--	129	6	99+	--	--	--	--	--		(438a)174
--	--	1500	600	60	--	--	--	185	--	Two stage; multistage plastic media	227
--	--	600	240	60	--	--	--	185	--	--	227
Dairy	--	220	55	75	1.54	7.8	9	8.1	--	30m³ filter, 10m³ clarifier. Single high rate	228
		390	122	69	1.37	7.8	9	13.0	--	"	"
		580	128	78	2.14	7.8	9	30.0	--	"	"
		760	410	46	2.05	7.8	9	38	--	"	"
		667	--	--	2.14	7.8	9	34.6	--	"	"
		703	198	73	2.05	7.8	9	34.9	--	"	"
		545	116	80	2.05	7.8	9	27.1	--	"	"
		462	217	59	1.62	7.8	9	18.1	--	"	"
		348	78	76	3.0	7.8	5.3	25.2	--	"	"
		600	114	81	3.3	7.8	5.3	48.6	--	"	"
		534	55	89	3.3	7.8	5.3	43.6	--	"	"
		392	41	90	3.3	7.8	5.3	31.7	--	"	"

Table 85 - Continued

Product or Process	Influent MGD	BOD, ppm Influent	BOD, ppm Effluent	%BOD Removal	Hydraulic Loading MGAD	Depth, ft.	Recycle Ratio	BOD Load, lb / 1000 ft³ day	Temp., °F	Remarks	Ref No.
Dairy	0.008	462	122	74	--	7.8	--	14.3	--	30m³ filter, 10m³ clarifier. Single high rate	228
	0.015	348	58	80	--	7.8	--	20.8	--	"	"
	0.015	600	60	90	--	7.8	--	36.1	--	"	"
	0.015	534	35	92	--	7.8	--	32.1	--	"	"
	0.015	392	32	92	--	7.8	--	23.7	--	"	"
Dairy	0.011	220	106	51	--	7.8	--	10.0	--	After clarifier of 10m³, ADF	"
	0.013	369	152	56	--	7.8	--	19.3	--	"	"
	--	580	--	--	--	7.8	--	--	--	"	"
	0.010	760	354	57	--	7.8	--	29.2	--	"	"
	0.012	667	--	--	--	7.8	--	31.7	--	"	"
	0.012	703	236	66	--	7.8	--	33.6	--	"	"
	0.012	545	90	82	--	7.8	--	25.5	--	"	"
Milk plant waste treatment	0.072	826	396	52	12.3	--	5.35	--	--	--	272
Condensing waste	0.03	537	215	60	--	36'x7'	--	--	--	--	308
Condensing waste	0.41	--	--	> 90	--	--	Yes	--	--	--	330
Dairy	--	300-10,000	30-215	--	15	43'd x	2.10	--	85-103	pH > 7.0 in; SS 250 in 250 inf. SS eff 50 ppm	371
Boiled milk				88	3.2	7'	none	40	77-92	A = .65**, k_1 = .141**	402
				78	20	7'	1.0	145	75-90	A = .30, k_1 = .199	"
				78	20	7'	2.1	110	70-90	A = .31, k_1 = .209	"
				88	20	7'	3.	75	78-88	A = .34, k_1 = .214	"
				90	20	7'	4.0	75	68-85	A = .37, k_1 = .230	"
				92	22	7'	6.0	80	78-84	A = .40, k_1 = .231	"
Dairy wastes with municipal	--	1475 dairy 634	149	50 90 overall	10.3	80'd x 5'h	2.75	155	--	Trickling filter & stabilization lagoon. SS reduced 86% NH_4, H_2PO_4 supp.	413
--	--	634	149	76	--	--	--	--	--	SS 77 ppm in, 51 out, Roughing filter .2 gph phosphoric acid supplied	413
Skim milk	--	--	--	80-90 (COD)	--	--	--	118	--	--	426
		1291	7	99.8	--	--	12	3.7	--	(from 1050) Single stage	439
Multiple	0.02-0.4	550 420	420I 175	-- --	99.8	10'	--	670	--	Aerated 2.5 ft³/gal; 2 stage	502
		660	500	25	99.8	10'	--	1460	72°	pH 6.1; 6.5 out, 2 stage	

Table 85 - Continued

Product or Process	Influent MGD	BOD, ppm Influent	BOD, ppm Effluent	% BOD Removal		Hydraulic Loading MGAD	Depth, ft.	Recycle Ratio	BOD Load, lb / 1000 ft^3 day	Temp., °F	Remarks	Ref No.
Skim milk	--	--	< 229	--		--	--	--	--	--	Experiment. Dosing cycle 20 min. (229) Reduce BOD shorter cycle	624
	0.021	--	--	69-87		--	24"d x 8'	--	--	--	--	635
Dairy effluent	-- --	-- --	-- --	70 90		.006 .010	-- --	10 6	33± 8.7	-- --	Recirculating --	641
	-- --	-- --	-- --	70 90		.011 .015	-- --	-- --	27± 6.8	-- --	ADF, weekly less capacity than recirculation, performance not entirely satisfactory	641
Dairy and municipal	--	--	< 40	--		6.7	60'd x 8.5'h	2	--	--	Two filters	696
	--	--	< 40	--		3.3	60'd x 8.5'h	2	--	--		
Multiple Prod. butter, drying	0.026			Filt 47.6	Overall 97.0	4.6		7.8	27.2	70-95	pH 6.8-8.0 Filter, clarifier, digester. Efficiency basis, raw + recycle	729
	0.024			52.6	97.6	4.4		8.3	-32.7	62-90	pH 6.5-7.8 "	"
	0.028			27.8	97.0	4.3		6.6	42.0	70-95	pH 6.3-8.2 "	"
	0.030			68.2	96.2	2.1		2.5	48.5	75-118	pH 5.8-9.2 "	"
	0.027			75.8	98.2	2.2		3.1	24.7	70-115	pH 6.5-7.5 "	"
	0.021			46 42	88.2	13.2I 20.4II		1.6	146	60-94	pH 7.2-8.3 Filter, clarifier, filt, clarify; efficiency basis, raw + recycle	
	0.014			61 64	93.9	13.2I 20.4II		2.1 3.2	195 136	55-100	pH 6.2-7.2 "	"
	0.014			62 44	92.7	13.2I 20.4II		2.4 4.3	196 133	60-88	pH 6.8-8.3 "	"
	0.015			70 35	91.3	13.2I 20.4II		1.9 3.5	150 80	58-97	pH 7.0-7.8 "	"
	0.012			62 55	94.8	13.2I 20.4II		2.7 5.0	180 124	75-98	pH 7.3-8.5 "	"
	0.011			58 60	95.4	13.2I 20.4II		3.3 5.6	155 117	70-95	pH 7.2-8.2 "	"
	0.0074			59 55	97.2	13.2I 20.4II		5.4 8.9	75 52	68-85	pH 6.8-7.5 "	"
	0.007			64 60	94.5	13.2I 20.4II		5.6 9.2	98 62	78-105	pH 6.8-7.5 "	"

Table 85 - Continued

Product or Process	Influent MGD	BOD, ppm		% BOD Removal	Hydraulic Loading MGAD	Depth, ft.	Recycle Ratio	BOD Load, lb/1000 ft³ day	Temp °F	Remarks	Ref. No.
		Influent	Effluent								
Milk P"A"	--	--	--	--	--	--	--	--	62-118°	Two filters. pH 6.3-9.2; 7.1 out	729
Milk P"B"	--	--	--	--	--	--	--	--	66-98	pH 6.2-8.4; 7.2 out	"
Evap. powder	--	--	.8	--	--	--	--	.2	--	pH eff. 7.5, 7.8, 8.2, 7.9;	735
Milk	--	--	.9	--	--	--	--	.12	--	SS e f 10, 21, 13, 22 respec-	
Cheese	--	--	1.4	--	--	--	--	.15	--	tively	
Butter	--	--	2.0	--	--	--	--	.04	--		
Dairy	--	--	--	--	--	6	--	17.8	--	Recommended ADF	740
	--	--	--	60-80	--	6	High	110-185	--	Recommended High Rate	
--	--	--	--	up to 90	12	6'h	8	37.0	--	--	769
Dairy	--	560-2880	5-54	95-99	--	87'd x 10'h	5	--	--	Waste diluted to 200 ppm by effluent sludge disposal problem	905
Dairy	--	--	--	"Sat."	50	3½-4½	--	High	--	Recommendation	990
Not specified presumed dairy	--	130	13	90	115*	--	--	14.8	--	pH 6.1, 7.4 ADF 5 day cycl- SS 140; 10 optimum; 300 ppm	1014
	--	860	17	98	115*	--	--	14.8	--	pH 5.0, 7.2 BOD max. tolerated SS 540; 50 20 min. dosing	"
	--	1130	5	96	115*	--	--	14.8	--	pH 5.0, 7.2 SS 820; 25	"
Municipal,	--	450	110	75 I	--	--	--	--	--	Two stage	1022
cheese	--	110	17	85 II	--	--	--	--	--		
Dairy factory	0.027	7200	1400	80	340* 8.7 (Calc)	16'h	--	712 (Calc)	--	Precipitation prior to filtration	1036
Dairy factory	0.012	3200	700	78	60* 2.3	4'h	--	59 (Calc)	--	"	"
Milk waste affluent from aerator	--	--	--	46	4400*	1.6d *21.6n	0.6 during	18.	--	Packing 8-16 cm 7 hr shift BOD_5	1088a,b
	--	--	--	50	8900*	"	0.8 during	37	--	"	"
	--	--	--	8	8900*	"	0.5 after	114	--	8-16 cm, loads are per shift	"
	--	--	--	17	13400*	"	0.5 all	84	--	"	"
	--	--	--	21	13400*	"	0.5 all	29	--	"	"
	--	--	--	43	13400*	"	0.5 all	48	--	"	"
	--	--	--	47	13400*	"	0.5 all	59	--	"	"
Dairy	--	--	--	45-50	--	--	2	44-62	--	Tower unit. 7 hour	1088b
Dairy & cheese	--	152 -3100	--	41 -68	--	--	--	36.3 opt.	--	Sed. gave addtnl 21-60 1. red'n Lact. removed 1001. N26-66% in T.F., 20-44 in sed.	1094
--	--	--	90-99	< 40	--	--	--	9.3-102	--	--	1133

Table 85 - Continued

Product or Process	Influent MGD	BOD, ppm		% BOD Removal	Hydraulic Loading MGAD	Depth Ft.	Recycle Ratio	BOD Load, lb 1000 ft^3 day	Temp °F	Remarks	Ref. No.
		Influent	Effluent								
Dairy wastes	--	--	< 30	--	20 -30	3.5 -6 h	5-10	< 37	--	"Industrial Experiences," 3-3.5 aggreg. wide open underdrains needed	1137
Dairy	--	--	--	--	16.7	--	--	349	--	2.6 hr retention 63 gal/day/ft^3 sedimentation 988 gal/day/ft^2 0.76 ft^3/ft^3 hr	1145a
Milk, butter, yogurt	0.019	730 -1210; 970 -1640*	--	--	--	--	Yes	37.6	--	Pretreatment in 85m^3 Speicher-tank, pH 6.7 6.6 hours setting	1208a
Milk, cheese, butter, yogurt	0.025	010 -2030	110 170	82.2 -92.0	--	--	Yes	39.5	--	pH 6.0-6.4	1208a
Milk, cheese, butter	0.160	260 -360	95 -260	13.1 -52.8	--	--	No	32.3	--	pH 6.1-6.5	1208a
	0.160	215 -400 *COD	65 -100	52.9 -75.5	--	--	No	7.1* *lb/1000 ft^3	--	pH 6.4-6.5 two filters in parallel	
German dairy plant	0.02	--	--	95	--	--	--	--	--	--	1211
Dairy wastes	--	417	50	88	--	35' x 8'	--	--	--	--	1213
Dairy	--	770	95	87	--	--	Yes	71.5	--	(#1135) two stage H. Rate	1238
	--	740	59	92	--	--	Yes	37.			
Dairy	--	445	--	--	1350*	--	1.59 I	73	--	(#729) two stage H. Rate	1238
	--	240	140	41 (96.5)	2090*	--	3.0 II		--	Raw 1190 ppm BOD	
	--	450	--	--	1350*	--	3.28 I		--	Raw 1620 ppm BOD	"
	--	190	75	60 (96.3)	2090*	--	5.63 II	78	--		
	--	210	--	--	1350*	--	5.4 I		--	Raw 1080 ppm BOD	"
	--	85	30	65 (97.2)	2090*	--	8.9 II	38			
	--	3270	110	99.6	333*	--	7.75	42	--	Single, High rate data from	1238
	--	--	--	96.3	158*	--	11:3	25	--	Morgan and Bauman (728-9)	
Dairy	--	300	10	96.8	(160g/yd^3 day)	--	Low	17.7	--	Recommended ADF	1240
Results of operation of 4 dairy plants	0.013 av.	600 av.	8	98.6	--	--	1	13	--	ADF	1240
	0.016 max.	1500 max.	30	98.0	--	--		32	--		
	0.02 av.	300 av.	3	99.0	--	--	1.5	2.5	--	"	"
	0.06 max.	700 max.	10	98.5	--	--		18.0	--		
	0.06 av.	250	4	98.0	--	--		12.5	--	"	"
	0.12 max.	400	6	98.5	--	--	1	3.9	--		
	0.04 av.	700	4	99.4	--	--	3	3.8	--	"	"
	0.09 max.	1600	15	99.0	--	--		19.2	--		

Table 85 - Continued

Product or Process	Influent MGD	BOD, ppm		% BOD Removal	Hydraulic Loading MGAD	Depth Ft.	Recycle Ratio	BOD Load, lb / 1000 ft³ day	Temp °F		Remarks	Ref. No.
		Influent	Effluent									
Milk washings	-- --	210 230	> 24 14	< 88.5 93.9	103* 156*	4.3h	--	11.8 -17.8	45.5 54.4	820 1280	ADF, Ellesmere 3 wks. 3/4 to 1¼" coke, pH in 5.8 to 7.1 out 7.8 to 8.2	1240
	-- --	210 110	7 11	88.2 90.0	203* 201*	"	-- --	"	59 50	600 210		1240
	-- --	170 300	15 14	91.1 95.3	203* 302*	"	-- --	"	44.6 63.5	230 600	16½ hr open of plant A/t 10 days o/t 10 days	1240
3 vol. milk washings 1 vol. whey	--	270	8	97.0	201*	"	--	"	65.3	700		1240
1 vol. milk washings 1 vol.	-- --	260 260	9 > 17	96.5 < 93.5	201* 302*SP	" "	-- --	" "	66.2 69.8	1010 650		1240
1 vol. milk washings 1 vol. whey	-- -- --	350 190 290	> 25 > 16 8	92.6 < 91.5 97.2	201*P 201*P 201*	" " "	-- -- --	" " "	54.5 50.9 64.4	780 450 950		1240
Whey washings	-- -- --	270 210 270	29 13 28	89.3 93.8 89.6	133* 165* 201*	" " "	-- -- --	" " "	54.5 51.8 66.2	780 560 830	pH in 4.6 to 5.1 pH out > 7.0	1240
Dairy	--	450 -1280	3 -10	99	--	--	3 5.5	9.3 -18.6	--		After Southgate (1035) 0.7 to 1.1 ft³/ft³ day. ADF 3 weeks	1247
Dairy Cheese	--	420 710	--	--	--	--	4 8.3	12.4 -46.7			After Eldridge (330?) 1.2 to 2.4 ft³/ft³ day	1247
Dairy	[illegible]	[illegible]	5	97 -99	.134	4@ 64 x 5.9	2	25	--		Baily Gate Plant, ADF 8 days	1247
Dairy	[illegible] -0.04	500	6 -10	99	.28	2@ 30 x 5.9	--	17.8	--		Crewe Plant ADF	1247
Cheese (2.3), Butter	0.01	1000	--	See Graph	.21	2@ 50 8.2	3.3	--	--		Rücklauf	1247
Dairy waste	0.029	-- --	-- --	63 #1 50 #2	-- --	-- --	-- --	162 #1 50 #2	--		Two filters in series	1250
Milk Municipal	0.07	312	82	73.7	--	4x90'x 5.5'h	-	15.0	--		Single stage	1263
	0.07	378 177	177 78	53.2 58.1 (79.4)	-- --	"	-	36.2 17.1	--		Two stage	1263
	0.67	329 84	84 59	73.8 32.1 (81.6)	--	"	--	30.2 2.9	--		Two stage dosing change	1263

Table S5 - Continued

Product or Process	Influent MGD	BOD, ppm		% BOD Removal	Hydraulic Loading MGAD	Depth Ft.	Recycle Ratio	BOD Load, lb / 1000 ft³ day	Temp °F	Remarks	Ref. No.
		Influent	Effluent								
Dairy waste	0.0016	847	70	91.8	9.7	--	10	31	--	Pilot plant studies Suggest BOD loadings < 37 for uniform results.	1272,3
--	--	260	--	92.5	--	--	--	25.5	--	Two-stage (#1040)	1286
Borden dairy	0.035	--	--	--	21.6 I 25.6 II	43.6'd 4'h	Yes	140 I 79 II	--	Design SS 170 in ppm (#111)	1287
Abbotts dairy	0.16				10.7 30.0	35'd 6'h	Yes	90 22.5	--	Design SS 640 in ppm (#111)	1287

*gal/yd² day

**$L/L_0 = A\,10^{-k,D}$ where L = BOD remaining at Depth D

SP Some Ponding towards end of period

P Ponding

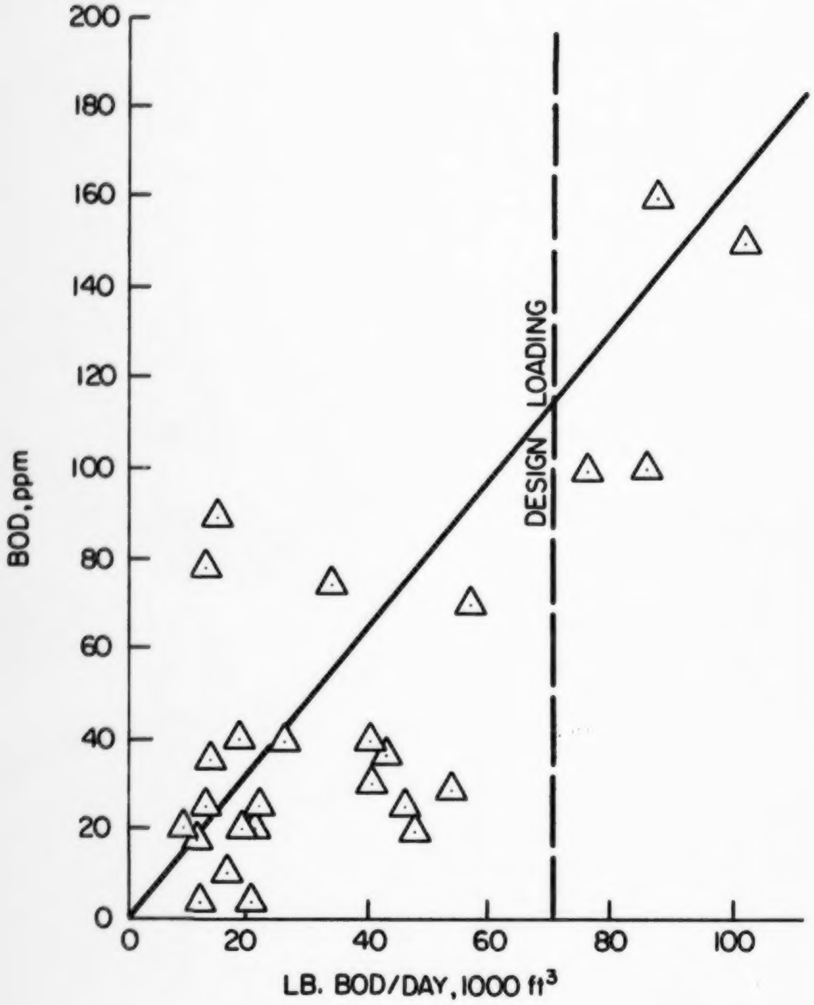


Figure 50 - Performance chart for two-stage trickle filter on dairy wastes (after Trebler and Harding (1133))

Figure 51 shows the probability of BOD removals for two different filtration systems after Christensen (228). Similar diagrams for still other systems are shown in Figure 52.

As in activated sludge systems, the variability reflects management, loading vs. design capacity and to some measure, the design approach.

Wieselberger (1247) reported the BOD removal performance for a trickling filter at various loadings. On this chart (Fig. 53) are also shown the loadings recommended by Southgate, his recommended design value, the design value of G. W. F. Hochbeipropfk according to Imhoff, and the average value in his experiment. The loading levels expressed in grams of BOD per day per cubic meter may be converted to pounds BOD per day per 1000 cubic feet by multiplying by 0.0815. An alternate scale has been provided for the convenience of the reader. The operating parameters for this plant are 22,000 liters per day, two-thirds to cheese and the remainder to butter and other products.

Here, increased volume loading may correspond to increases in hydraulic loading.

Loading Sensitivity

At present there is not sufficient information to fully interpret such variation, but the literature indicate sensitivity to hydraulic loading, some sensitivity to BOD loading, and sensitivity to change in salt or lactose lev[illegible]

The results of a number of experimenters including Schulze (966, 967, 964b, 1247) show sensitivity to increase in hydraulic loadings. Schultz has shown that a four-fold increase in hydraulic load would give efficiencies about half those at the lower loading.

Quirk et al. (857b) also found in one experiment that the trickling filter was responsive to flow change and would require a six-to eight-hour time to adjust to a 250% change in flow rate when treating "whey" wastes.

Another possible source of variability in performance is the variation in BOD loading. However, the data of Schulze (966, 967, 964b) show that BOD loading will have only slight effect on the BOD efficiency of a trickling filter. For example, Schulze (964b) found that increase in organic load from 37 to 148 pounds BOD/1000 ft^3-day did not change the efficiency significantly. Here the hydraulic load was 5.5 mgad. The same observation was true for increased loading from 185 to 370 pounds/100 ft^3-day.

Morgan and Baumann (729) report a reduction of BOD removal efficiency from 98.2 to 96.2% when the raw BOD loading per acre foot-day was increased two-fold from about 25 to about 50 lb/1000 ft^3-day. A similar reduction removal efficiency from 97% to 93% was reported when

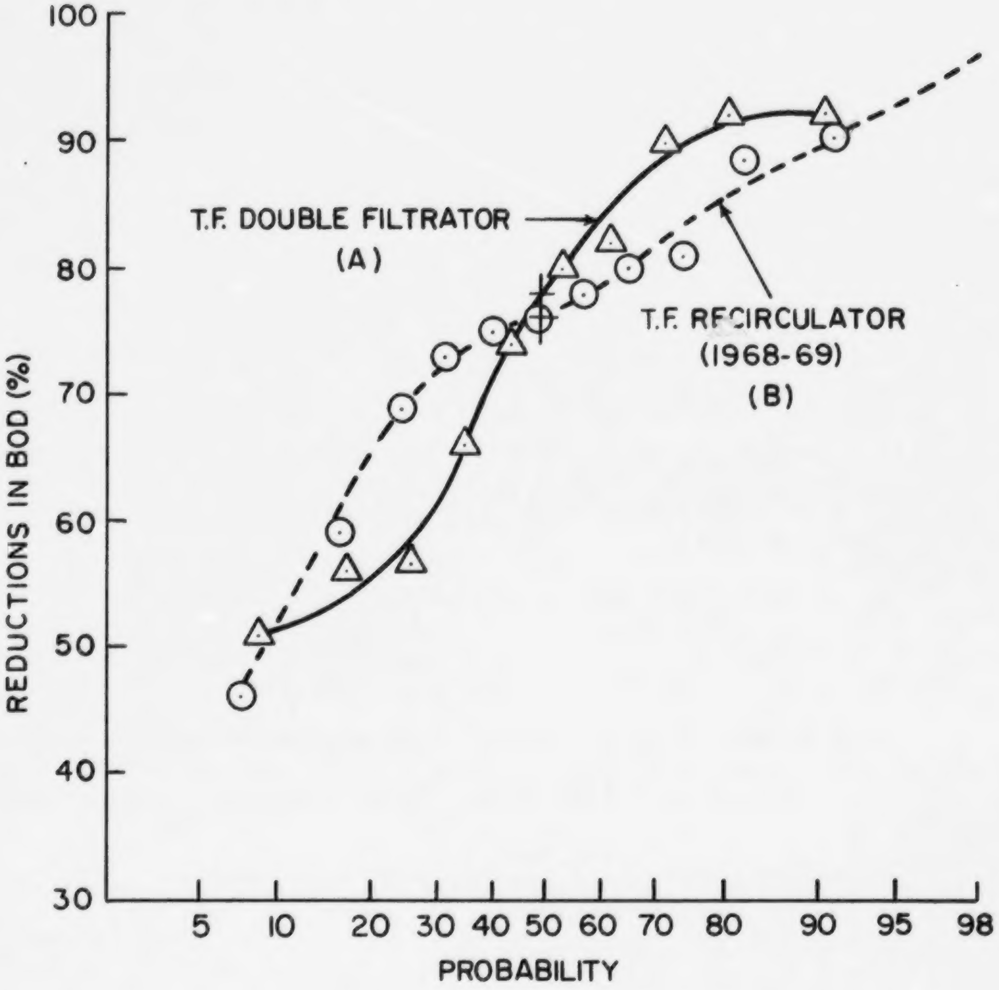


Figure 51 - Performance of recirculation and alternating double filtration systems (after Christensen (228))

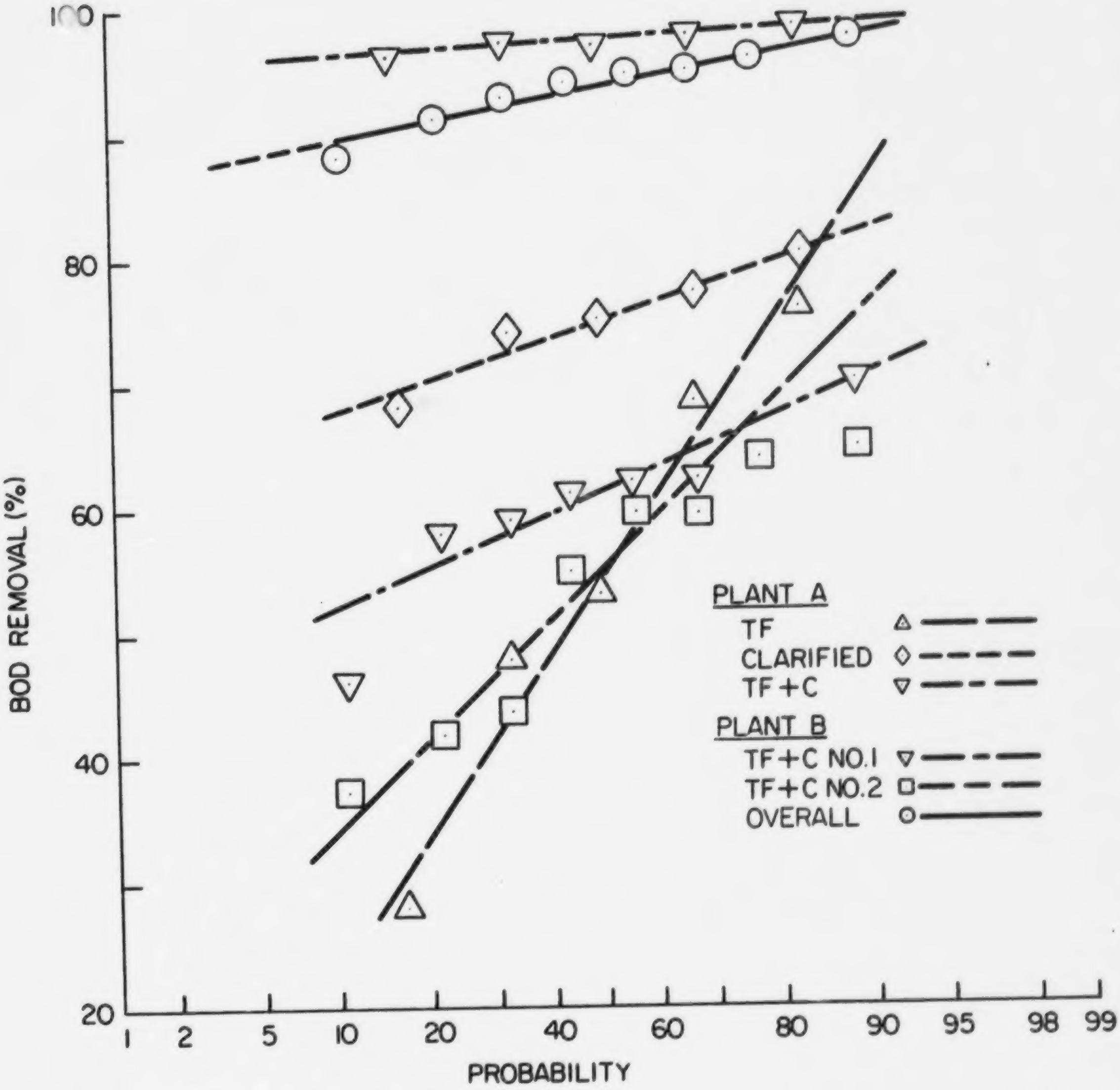


Figure 52 - Probability of BOD removal for the trickling filter (TF), clarifier (C) systems studies by Morgan and Bauman (729)

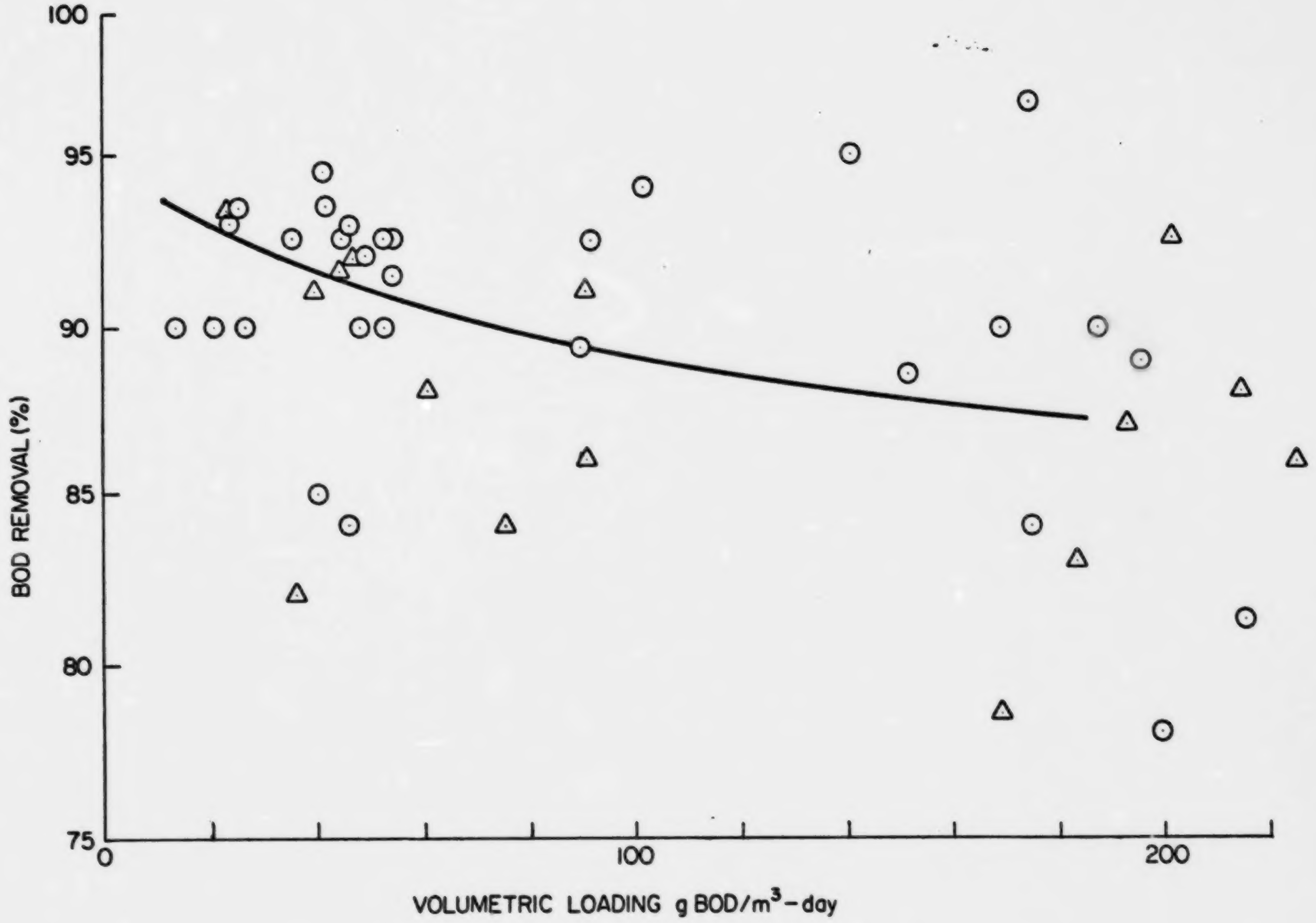


Figure 53 - Performance of a trickling filter (after Wieselberger (1247))

the BOD loading was increased from about 3200 lb/acre-foot-day to about 8800 lb/acre-foot-day. In the first instance the hydraulic loading increased over two-fold. In the second case the hydraulic loading was maintained constant.

Trebler et al. (1141) using dairy waste, loaded their experimental filters with up to 925 pounds of BOD per 1000 ft^3-day and the efficiency curve did not appear to decline. Schulze (965, 6, 7) suggests that the practical limit may be filter clogging, however.

The literature does not seem to be of one mind in this issue. Eckenfelder (312a) and Rich (877a) show BOD removal fractions which are inversely proportional to about the two-thirds power of the hydraulic loading are only indirectly sensitive to BOD loading. (See also Eqs. 39, 40.) But the National Research Council data show an emperical relationship between BOD removal efficiency and the intensity of loading expressed in pounds of BOD/acre-foot day.

Rich (877a) reports the removal efficiency in terms of the following relationship

$$\frac{C}{C_o} = 10^{-ky^m/(Q')^n} \qquad [44]$$

where C = concentration of organics in the effluent
C_o = concentration of organics in the influent
y = depth of filter
Q' = hydraulic application per unit area filter surface
k = constant
m, n = experimental exponents

Rich (877a) reports the values of exponents m and n will vary with the type of filter used and the flow characteristics through the filter. Values of 0.3 to 1.5 with a mean of 0.67 and n values varying from 0.2 to 1.10 with a mean of 0.5 have been reported by Eckenfelder (311c).

Scatter diagrams for removal efficiencies as a function of surface hydraulic and BOD volumetric loadings are shown in Figures 54 and 55.

Schulze (967a,b) has shown, through use of accepted empirical models for trickling filter performance, that recirculation does not improve the quality of the final effluent except under relatively high incoming flows in a single filter. In all other cases it appeared that the gain by dilution of the incoming BOD is lost by a decrease in efficiency of treatment of the material actually applied to the filter due to the higher hydraulic load. Similar conclusions were reached by Howland (432a) in his more extensive treatment of the problem. It appears that increases in performance due to recirculation must be associated with better distribution equalized hydraulic loads unless there is clogging or perhaps flaws in the models used.

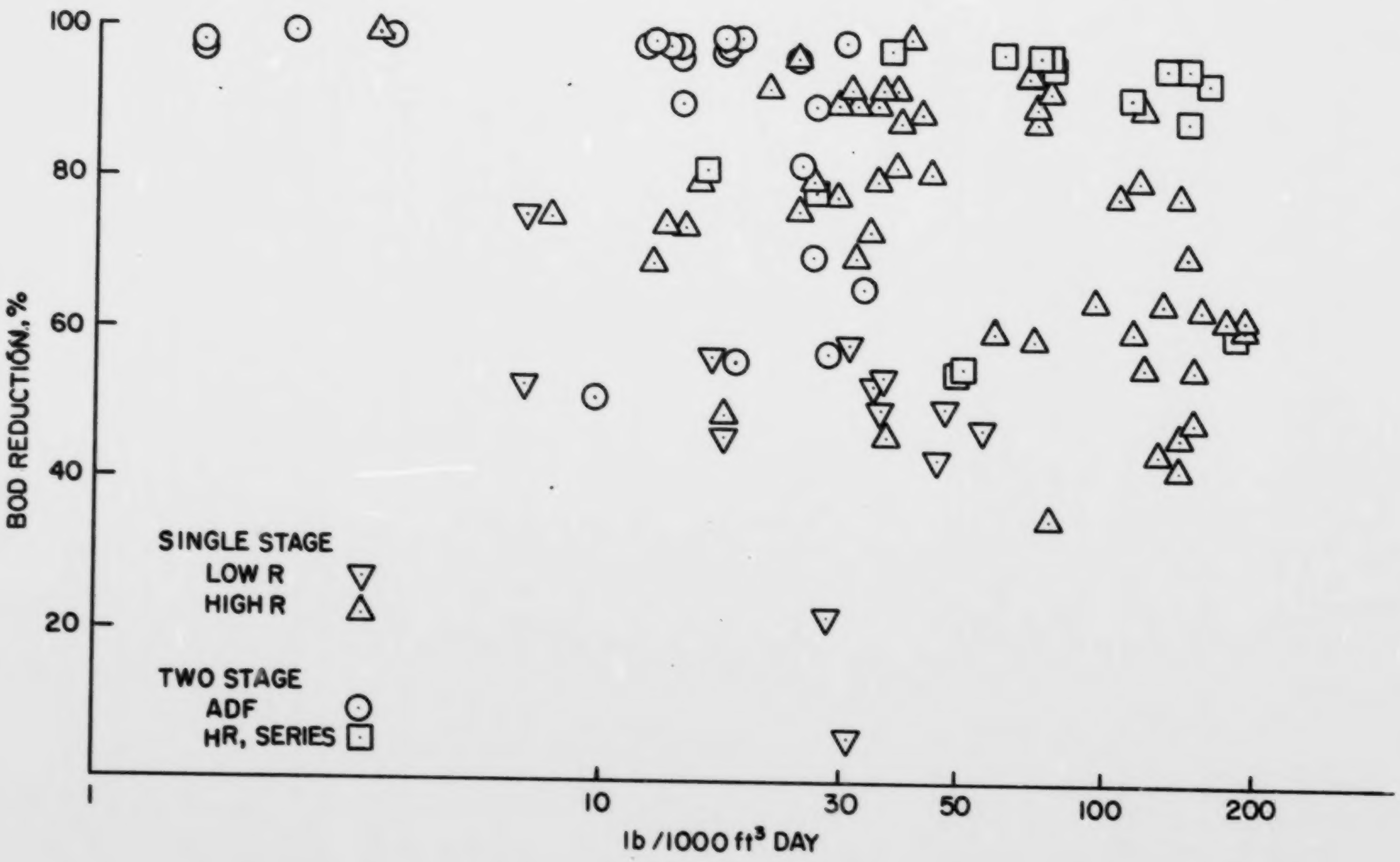


Figure 54 - Scatter diagram of trickling filter performance (after Table 85)

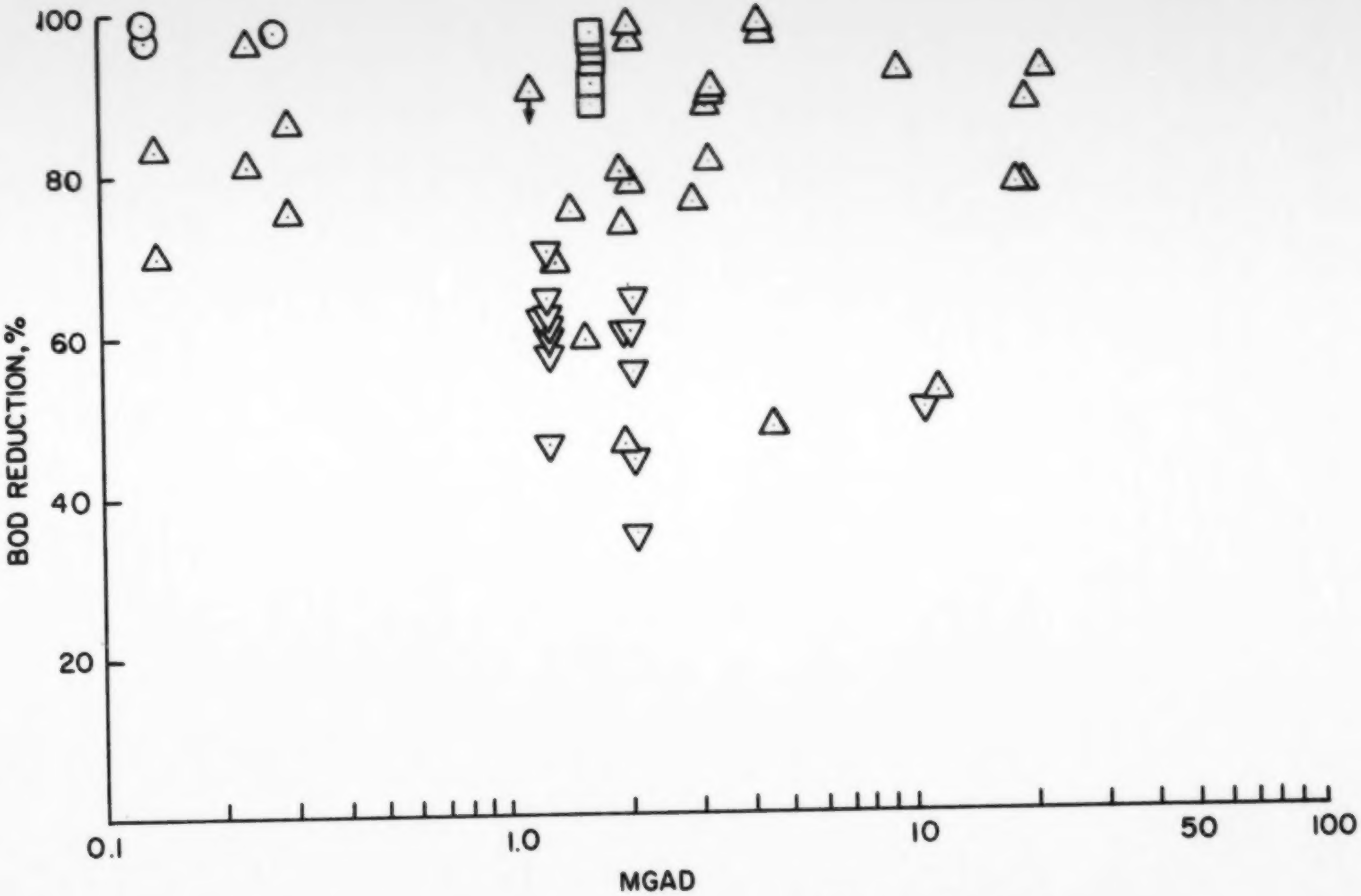


Figure 55 - Scatter diagram of trickling filter performance
(after Fig. 54 and Table 85)

A position similar to that of Schulze and Hawland was taken by Quirk et al. (857b) in their scale-up of laboratory systems.

Lawton and Eggert (610a) studied the response of filter slimes to the influence of high salt and lactose shock loadings. Slime acclimatized to raw sewage gave poor BOD performance when shocked with about 240 ppm of a lactose broth but recovered within one day. Slime growth developed readily even with high salt concentrations if BOD concentrations were not excessive. The development of the slime growths was retarded by the presence of saline wastes and gave somewhat lower BOD removals.

Filter growths acclimatized to low salt wastes were adversely affected in performance and often sloughed when high salt loads were applied to them but became acclimitized in a short period of one to five days. In a similar manner slimes acclimitized to high salt loads showed a shock effect when subjected to low salt wastes but generally recovered within one day.

In all cases waste loadings in excess of 1500 ppm did not permit the normal growth of filter slimes in the absence or presence of sodium chloride. In many of these tests sewage-whey mixtures were used.

Industrial Experiences

Harding (432) reports that trickling filters have been used for many years for the treatment of dairy waste and had been reported to have relatively high capital cost, relatively low operating costs, and an ability to absorb shock loads yet give BOD reductions of 80-93%. High rate, two-stage, recirculating trickling filters are said to have given better results than standard filters. Clarifiers and sludge digesters are required. High BOD concentrations are reported to have given excess slime growth in the filter medium with consequent ponding.

Trebler and Harding (1138) report that the same low loading rates of 18.5 pounds BOD per 1000 ft^3-day are preferable for either the high rate (5:1 to 10:1) recirculating filtration or the alternating double filtration. The high rate trickling filters are said to be preferable due to their relative freedom from odor and filter fly problems when maintained and not overloaded. Alternating double filtration systems are said to require less power, produce less ponding, and to produce less sludge volume.

Stander (1049) refers to reports by Eldridge that the satisfactory treatment or the average milk waste requires recirculation ratio of about 8-10 times. Alternating double filtration was reported to have eliminated the problem of ponding at higher BOD loads. Results of the Water Pollution Research Laboratory in Great Britain are reported to indicate that alternating, double-filtration systems are much less subject to upset by sudden increases in waste strength then are activated sludge units. They further report that whey washing are treated with more difficulty than milk washings.

Scott (990) reports satisfactory industrial experiences with trickling filters with high rate recirculation for flows of approximately 50 million gallons/acre/day at depths of 3-1/2 to 4-1/2 feet. A loading rate of about one-half BOD per cubic yard of filter material is recommended. Installation costs are said to be high although operating costs are reported to be lower than for aeration.

Fraser (37) reported odors from high rate single stage trickling filter treating effluent from a dairy factory in Australia. He proposed the odors were due to anaerobic metabolism in the thick slime layers encountered with dairy waste. To prevent such odors Quirk et al. (857) used an air flow of 40 ft^3/gal and a laboratory ozonator as well. Odors were reported during the experimental work only during loadings above 0.036 pound BOD/ft^2, day on the prototype at loadings of above 1000 pounds BOD/1000 ft^3, day.

Rugaber (905) reported on operational experiences for a trickling filter applied to the waste from an evaporated milk plant. He reported problems with ponding and channeling and the accumulation of sludge. Aeration of the waste storage tank ahead of the treatment unit did not give appreciable BOD reduction but did lead to reduced odors. He concluded with the cost of construction of the plant at the time of his report, 1951, that trickling filter systems are not the economical answer to the waste disposal problem.

Wheatland (1240) recommended design loadings for alternating double filtration plants of 17.7 pounds of BOD per 1000 ft^3, day which is equivalent to a hydraulic loading of 160 gal/yd^3, day when the waste has a BOD of 300 parts per million. Such a plant was reported to have the capacity of consistently producing a final effluent of about 10 parts per million. This is a design efficiency of 96.8% for this low influent concentration.

Wittmer (1263) made one of the few reports of the application of alternating two-stage filtration to sewage and milk waste treatment in the United States. (Data of the operation of these filters as a single stage, two-stage with the same dose in sequence or two-stage with a changed dose in sequence are reported in Table 85).

Two-stage filtration without a change in dose in sequence resulted in a heavier and darker colored growth from the primary filter than that observed on the secondary filter. The darker color was associated with the almost dissolved oxygen reported in the first-stage filter. Heavy sloughing was usually encountered at all times using this two-stage filtration. Single stage filtration produced a satisfactory effluent but with a 6% poorer efficiency than for the two-stage operation without change of dosing sequence and about 8% less than that for the two-stage operation with the improved dose in sequence. Two-stage filtration was found to be an effective method of BOD removal; being slightly more effective when the dose in sequence is periodically reversed and suggests that maybe some apparent benefit was derived in the control of ponding and decrease in flies.

Muers (740) recommended a BOD load of 17.8 pounds of BOD/1000 ft^3, day to give satisfactory performance. He maintains that the alternating double filtration system developed especially for treating dairy wastes is so much more efficient in terms of BOD load capacity per 1000 ft^3, day that it would always be advised in preference to a single-stage filtration plant. He further advises the application of alternating double filtration for municipal systems in which dairy waste performances are a significant part of the load. He reported that it has been reported that, with single filtration, even at lower loadings than for sewage, there is a tendency for excessive film growth due to the ease with which milk components could be broken down by bacterial action.

For high rate filtration systems using large filter media on the order of 3 inches, and hydraulic loadings of about 500 gal/yd^3, day, very high BOD loadings were claimed not to cause choking or ponding. Loadings of 110 to as high as 185 pounds of BOD/day/1000 ft^3 are reported to remove 60 to 80% of the influent BOD. The prime use of this approach is for roughing filters ahead.

Experiences with Whey

Muers (733) studied the treatment of a 10% solution of whey and tap water (4650 ppm) using laboratory trickling filters. This waste was applied at application rates of 50-200 gal/yd^3, day with removal efficiencies from about 73 to about 96%. For a given feed concentration, the highest efficiency and best effluent were obtained with the lowest rate of application; for a given rate of application, the highest efficiency and best effluent were obtained with the lowest concentration.

Decreasing the carbon/nitrogen ratio of the feed by addition of ammonium carbonate or sodium nitrate reduced the efficiency. Further, neither replacement of part of the whey by skim milk nor removal of part of the albumin nitrogen had any adverse effect. Preliminary fermentation of a portion of the lactose and whey produced no ill effect on filtration efficiency. The addition of lime, however, did reduce the efficiency.

A second biological filtration was found to be a relatively ineffective means of oxidizing residual material left in the effluent from the first filtration.

Ingram (500, 502) operated a deep filter pilot plant on waste containing whey. He advocated hydraulic loadings in excess of 70 billion gallons per day to assure complete distribution and to maintain freshness. Results showed 67% removal of BOD at a loading of 300 lb/ft^3, day. Under these operating conditions odor problems were not encountered.

Schultz (964a, 964b 967) has made a substantial contribution to the waste treatment literature in his application of biological filtration for the treatment of whey bearing waste. He employed a laboratory test stand to obtain data for verification of descriptive mathematically formulations. Culture growth characteristics were also observed.

Quirk et al. (857b) made a laboratory study of trickling filter performance using an inclined plane and followed this with a larger inclined plane and packed column systems.

The lab-scale studies were made with computer-assisted modeling to project removals in the order of 95% for a multistage treatment system.

In two instances, the pilot plant gave BOD and COD efficiency of 86 and 84%, respectively, but the range of treatment efficiencies observed was from 0 to 86.7% and efficiencies in the order of 50 to 60% were much more frequent. The erratic performance observed in the operation of the pilot plant is of some concern. This variable performance was attributed to extensive slime growth encountered at high loadings. Variable performance, black sludge and poor draft, as indicated by smoke test, were taken as evidence that the pilot plant was occasionally affected by anaerobic conditions.

Whey treatability was expected to exceed that of the average industrial effluent when packed, open, oriented filters are employed. The addition of ammonia nitrogen increased the rates of biodegradability but the addition of ferric ion did not increase treatability as had been found by others. The inherent acidic reaction whey effluent was said to cause no problem in aeration from 7.0 pH; aeration from 7.0 to 4.5 resulted in an increase rather than a decrease in BOD removal rate. Because of the prolific filter sludge growth expected they suggested a filter with a high porosity and low susceptibility to sloughing of filter slime.

Schulze (966) has studied the performance of dairy wastes on a screen model of a trickling filter. He found that the addition of whey to municipal wastes to bring the combined waste to a BOD of 500 or more quickly built up the biological film thickness from 1/8 inch to 1/2 inch. Consequently, he recommended that high recirculation rates and filter media without narrow or irregular passageways be used for such strong industrial wastes.

Antonie and Welch (121) (1232, 1232a) have reported on preliminary results of a novel biological process for treating dairy and whey wastes which employed a rotating disc as a means of aeration and carrying a biomass. The concept shows potential for small cheese plants. Further work is being done.

Plastic Media

Small opening plastic media were used unsuccessfully in the brief trials of Quirk et al. (357b). Others have attempted their use and report some success.

Askew (128a) has reported the main advantages of plastics to be space saving, economical, ease of construction, cheap lightweight mode of materials, and ease of automation. He reported that with a treatment volume of 0.25 billion gallons per day the strength of 1500 parts per million complete biofiltration capacity could be installed for less than 45,000 pounds at current prices, compared with 80-100,000 pounds for the larger volume of low rate conventional biofiltration. An area of approximately 130 yd^2 would be required for a high rate biofilter plus some 600 yd^2 for conventional final stage where alternating double-filtration beds would require nearly double the space.

Wheatland (1240) reported on the comparative performance of two seven-foot-deep, pilot scale filters, one containing a two-inch granite medium and the other a fabricated plastic medium (see Table 87). Reconstituted milk was applied at the rate of 200 gal/yd^3, day without recirculation. The whey strength was gradually increased for a period of months from a BOD of about 900 parts per million to one of approximately 2000 parts per million. Although the specific surface area of both types of medium was the same, that is about 20 ft^2/ft^3, the granite medium initially produced the better quality effluent, but as the loading increased the performance of the two filters became comparable. The granite medium was reported to have lead to the accumulation of considerable quantities of biological film and at higher loading soon approached the condition of ponding (perhaps due to the z in material, and no ADF or recycle). The plastic film, in contrast, showed a smaller accumulation of film and was never in danger of blocking.

Table 87 - Comparison of the Performance of Granite and Plastic Media Treating Simulated Milk Waste (Rate of Application of Waste 200 gal/yd^3/day (1290 ℓ/m^3/day)) after Wheatland (1240)

	BOD					
			Settled Effluent			
			Granite Medium		Plastic Medium	
Monthly Period	Milk Waste (mg/ℓ)	Loading lb/yd^3/day	(mg/ℓ)	% Removed	(mg/ℓ)	% Removed
1	927	1·85	161	82	427	54
2	1060	2·12	188	82	270	74·5
3	1215	2·43	371	82	450	63
4	1420	2·84	544	62	495	65
5	1930	3·86	787	60	803	58

Wheatland (1240a) recently reported on experiments with high-rate biological filters with the Water Pollution Research Laboratory at Stevenhedge. A filter packed with Flocor medium was used to treat dairy waste for a small cheese factory with a 16-hour operating shift. BOD was applied at a rate of 138 pounds of BOD per 1000 ft^3/day. Reductions on the order of 87-93% in COD were reported when the operating temperatures were about 20°C. In studies later than those reported in (1240), Wheatland reported troublesome growths on the filter. When questioned, he replied that although these growths had been found on small scale research equipment they had not been significant on a large scale plant. The growths were attributed to under-irrigation and lack of nutrient chemicals. A low-efficiency high-load system arranged in stages was suggested as the most efficient way to handle a given volume.

Chipperfield et al. (227) reported the application of multi-stage plastic media treatment plant systems to dairy wastes.

The first application was to the effluent of a cheese-making factory with a discharge of 0.015 million gallons per day concentrated in a 10-hour production-processing period. An intermittent loading of as high as 230 pounds BOD per 1000 ft^3/day gave treatment efficiencies consistently above 80%. No balancing facilities were afforded. The discharge from this roughing filter was treated by a final percolating filter.

In the next installation the plant had a BOD concentration of about 1500 parts per million and was treated in this system of successive flow balancing tanks, fat and curd separation, two plastic media roughing stages in series with the recirculation and interloop solids separation followed by low rate ADF filters, final clarification and perhaps tertiary treatment. pH control was not normally required. Storage periods were short. The wastes were short. The wastes were reported to be theoretically nitrogen deficient but supplementation was provided only during peak periods of loading, which corresponded to the summer months when trickling filters generally give better performance. A similar design approach was reported by Askew (128a). This approach is said to require less ground area.

Treatment Problems

The primary operational-design problems with the application of high-rate recirculating trickling filtration appear to be: (1) the inhibition of microbial activity, the precipitation of casein, and the low pH caused by the rapid conversion of lactose to lactic acid in the holding tank prior to first stage primary filtration, (2) low activity, (3) clogging of filters and the inhibition of development of natural biological film with consequent odors, ponding, and sloughing, (4) poor sludge settling, and disposal problems, and (5) sensitivity to hydraulic and shock loadings.

The first problem can be overcome by preaeration. The second problem, reported industrially but not evident in the Quirk et al. study, can be reduced by management of salt and whey discharges and by designs to maintain optimum waste temperatures. The third problem appears somewhat more pressing.

One approach has been indicated by Trebler and Harding (1133) who reported that the old-fashioned alternating flow tricklers appeared to give satisfactory performance but tend to clog up and he comments that in the newer rapid-flow recirculating trickling filters coarser material from 2-1/2 to 3-1/2 inch size has been found far more satisfactory. In these instances this reduced clogging and relative freedom from flies and odors. (The larger diameter filter materials were said to appear to be capable of handling large shock loads occasionally without too much upset. The authors also commented that their system operated at the higher BOD loadings of about 100 pounds/1000 ft^3/day would lead to odors.) In this approach the influent BOD was reduced and the sensitivity to hydraulic loading was decreased by high recycle ratios. Further, larger air channels were produced.

The approach applied extensively in England is alternating double filtration. This is two-stage, low recycle rate filtration, with or without intermediate clarification. The period of alternation is generally one to three weeks; perhaps shorter for higher lactose wastes and for the smaller (< 2-1/2") packings. It is interesting to note that this alternation period is shorter than the period to develop clogging in the Quirk et al. (857b) study on the acclimization period for activated sludge in the study of Adamse (6).

Ingram (502) recommended: 1) For year-round operation, the filter unit should be enclosed. He observed that a system performed much better at an average temperature of 18°C than at 12°C; 2) A means of maintaining 20-hour flow was mandatory to maintain the filter material; 3) The distribution devices should be nonclogging providing for continuous discharge. He commented that nozzles used in the pilot plant were adopted from commercially available sprinkler heads and were easily clogged; 4) Debris and solids should be filtered; 5) Air blowers should be capable of providing 0.5 ft^3/air/gallon of raw waste of filter depth.

ANAEROBIC TREATMENT

Anaerobic processes were at one time used in the septic tank treatment of the waste from very small dairies. As these dairies grew most turned to aeration, then conventional activated sludge units. Since that time there has been relatively few reports of anaerobic treatment of dairy waste or the effluent from activated sludge.

These few reports, however, have shown that treatment efficiencies above 90 percent can be obtained in conventional (1043, 690, 867), anaerobic contact (954) and rapid absorption process (954). Somewhat lower efficiencies have been reported in an anaerobic filter used to treat a milk-whey waste. The Pien process of aerobic fermentation, anaerobic digestion, followed by chemical coagulation, has also been reported to give high BOD removals (806-810, 659, 1085). Parker (787a) has recently reported some success in anaerobic fermentation of whey.

The Biological Process: The biological processes for anaerobic fermentation appear to be quite complex as indicated by the studies of Lembke (620), Poulsen and co-workers (841, 21, 22) and Kiss and Timar (565).

Lembke (620) followed the milk waste treatment through a 24-compartment septic tank. Lactic acid bacteria predominated in the first and second tanks and rapidly decreased in the third and fourth tank. Lactose also decreased rapidly in these same chambers, until it was absent by the third tank. The acid which was produced disappeared in the final series of tanks. Many cultures were isolated, including coli, which became the main flora together with a large number of molds. Ammonia appeared in the third compartment, then had disappeared nearly completely by the fifth compartment. Formation of hydrogen sulfide reached a maximum by the thirteenth compartment. Organisms capable of breaking down fat were said to be consistently present. Moreover, the fat was reported to be decomposed in the early stages of the process.

Andersen and co-workers (22) observed that in the first 24 hours, pH fell from 7.2-7.3 to 4.6-5.6 (lactose fermentation). An equilibrium was established at a pH of 5.7. The sludge layer reached a constant depth. About 70% of total N in the skim milk and water mixtures (and less in whey mixtures) was converted to NH_3-N and lower organic acids. The anaerobic fermentation produced a 10-30% loss of C, probably as CO_2 and methane. Marked changes occurred during three days of anaerobic fermentation without actual purification making waste more susceptible to biological oxidation.

Poulsen et al. (841, 21, 22) followed the breakdown of 12 and 5 percent skim milk-whey wastes in a three-flask digester having one-day detention time per flask. The lactose disappeared in the first flask and the pH dropped to about 5-5.6. In the second and third tanks there was considerable breakdown of protein. The volatile acid concentration increased; some CO_2 and CH_4 developed.

Kiss and Timar (565) followed an anaerobic fermentation of 1 percent milk solution. A rapid decrease in pH from 7.6 to 5.6 was noted during the first three days. This was followed by a steady rise in pH to 6.0 in three days and 6.8 in twenty days. The protein-N content decreased by 80 percent, the lactose content by 100 percent, the $K_2Cr_2O_7$ demand $<$ 70 percent, the $KMnO_4$ demand approximately 80 percent and the BOD 65-70 percent in three days.

Buswell et al. (198a) reported influent volatile acids averaging about 630, 1300, and 1500 ppm for skim milk, buttermilk, and whey, respectively, with effluent volatile acids of about 1300, 1600-1850, and 1700-1750 for skim milk, buttermilk-whey, and whey, respectively. When the fermentation "went sour", volatile acids increased and gas production decreased. At such times the predominate acids found were propionic and acetic, with traces of lactic and formic acids. The highest lactic acid concentration found was about 40 ppm.

Studies of anaerobic pathways indicate that the volatile acids are a metabolic intermediate which, in turn, may be further broken down into methane, and carbon dioxide.

These processes are shown schematically in Fig. 56.

Kinetics: In a gross sense the biological process can be divided into a sequence of two simple reactions, with the controlling enzymatic step dominating the others. This sequence of reactions analytically like the formation of and enzyme-substrate complex and its subsequent dissociation into productate and enzyme. Therefore, it is not surprising, Stewart and co-workers (9c, 25b, 1058a,b; 67c,d) have applied this relationship as shown in equation [45].

$$\frac{dF/dt}{X} = \frac{KL}{K_s + L} \qquad [45]$$

In the 1960 review of literature in J. WPCF, the findings of Schroepfer and Ziemke (954), with respect to the absorption and stabilization of skim milk waste, were said to agree with the Michaelis-Menton theory of enzymatic reactions.

No explicit data with respect to apparent reaction rates; i.e., maximum reaction rates, k, or concentration at half the maximum rate, Kx, have been found in this search of the literature. Although industrial loading data give rule of thumb information, kinetic data is required for improved reactor design.

Data for other carbohydrate-protein systems may give an estimate of the order of magnitude of the kinetic parameters and the reaction orders to expect for dairy wastes.

For systems in which the carbohydrate is glucose or dextrose and the protein fraction is tryptone or peptone extracts, Pearson (796b) has cited K_s values from 164 to 6700 for an average of 4100 ppm. This evidence suggests that zero order substrate removal will be encountered only when by-products such as whey, or buttermilk whey, product returns, or first rinses or first washes are treated, for only then will L/K_s be on the order of 10. Further, most dairy effluents would be expected to be fractional order, for the estimated criterion for first-order waste concentration dependence is $K_s/L \approx 10$ or $L < 400$.

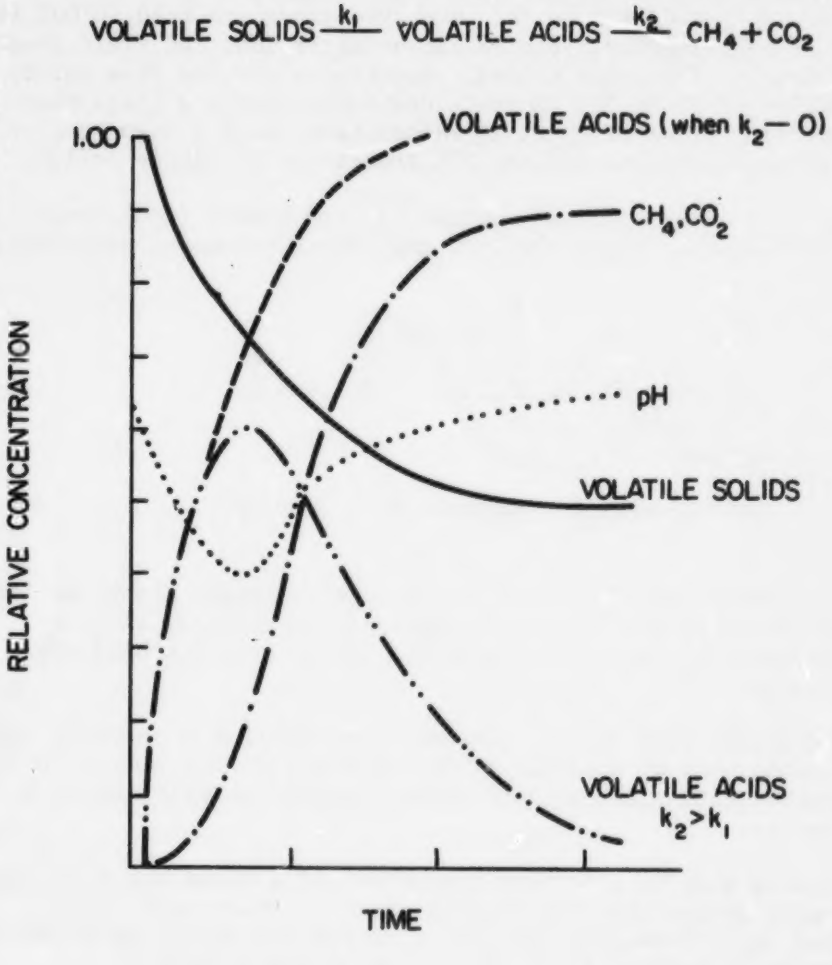


Figure 56 - Schematic diagram of relative concentrations during the course of an anaerobic fermentation (after Malina (651a) and Andrews (256))

If the growth rate for the methane bacteria is not sufficiently larger than the critical retention time of the solids, θ_C, then these organisms will "wash out." The consequence is the appearance of higher volatile acid concentrations and more highly objectional sulphur compounds in the effluent. The literature (1043a, 610b, 1123a) indicated just satisfactory residence times, θ_C^{min} of 2, 2-5 days, 2.7, 3.2, 7.5 days for methanol, acetate, butyrate, primary and activated sludge, and propionate fermentations. McCarty (670c) has suggested operation with safety factors, θ_C/θ_C^{min} of 2 to 10. Such processes are said (670c) to be high-rate or high-loading, require closer attention, and yield lower process efficiencies than conventional processes operating with safety factors, θ_C/θ_C^{min} of 10 to 70. Eckenfelder and co-workers (314) have suggested detention times of about 10 rather than about 5 days to give perhaps 90% as contrasted to perhaps 70% reduction of organic solids.

Response to Loading: Indeed, Schroepfer and Ziemke (954) found that at higher loadings, pound BOD/ft^3, day, the BOD removal efficiency were reduced.

At 35°F

$$\text{BOD removal \%} = 101.1 - 50.8 \text{ Loading} \tag{46}$$

where r = -0.94 and at 25°F

$$\text{BOD removal \%} = 103.6 - 146.2 \text{ Loading} \tag{47}$$

where the correlation coefficient r = -0.84 for a contact stabilization process in which the mixed liquor was degassed, sedimented, and the sludge was returned to the heated digester. These relationships are also shown in Figure 58.

The operational data for BOD removal as a function of contact unit loading indicated that at loadings of 0.2 lb/day/ft^3 efficiencies of 90% would be expected with packing plant wastes, synthetic milk wastes or fatty acid wastes.

It is interesting to note that the effect of loading was more pronounced for milk wastes than for packing plant or fatty acid wastes. The latter had only 2% removal percentage change for each 1/10 pound loading increase as contrasted to 5% for the synthetic milk.

A brief experiment was conducted to determine if the BOD removal could be improved by increasing the solids content as kinetic relationships so suggest. The solids were increased to the contact unit from about 1500 ppm to 3000 ppm through the use of centrifigal separation with no apparent improvement noted. Schoepfer and Ziemke suggested that at an extremely high solids concentration there is difficulty of mixing and there is the possibility of accumulation of metabolic products which inhibit (or repress) the activity of the organisms.

They also studied a rapid absorption system in which mixed liquor contacted fresh waste, the mixture was degassed and separated by sedimentation with the solids returned to the digester. For this system the data show poor correlation between the BOD removal and contact unit loading. (See Fig. 57.) Here

$$\text{BOD removal \%} = 89.6 - 70.4 \text{ Loading} \qquad [48]$$

where the correlation coefficient is only -0.24.

This flow system gave approximately 80% removal of BOD at contact loading 0.13 lb/ft^3 or a sludge age of about five days. Under similar operating conditions the anaerobic contact process gave approximately 95% BOD removal.

Response to Sludge Age: In the operating range of about four to about eight days sludge age, Schoepfer and Ziemke (954) found linear regression relationships between percent BOD removal and sludge age, as shown in Figures 58 and 59. For the contact process these regression expressions were

$$\text{BOD removal \%} = 80 + 2.23 \text{ sludge age} \qquad [49]$$

with a correlation coefficient 0.89 and at 25°C

$$\text{BOD removal \%} = 72.7 + 1.19 \text{ sludge age} \qquad [50]$$

with a correlation coefficient of 0.84.

These regression relationships were not expected to extend through low sludge ages for the author suggests that there would be no BOD removal at 0 sludge age.

Over the range of the detention periods of this study there did not appear to be any correlation between the detention times and the contact unit or the adsorption unit, based either on raw or total flow with BOD removal.

For the rapid absorption process the correlation between BOD removal and sludge age was also poor, with the correlation expression of

$$\text{BOD removal \%} = 67.4 + 2.16 \text{ sludge age} \qquad [51]$$

with a correlation coefficient of only 0.37.

The minimum sludge ages reported above θ_C^m suggest that Schoepfer and Ziemke (954) were operating at two to three times the minimum at washout.

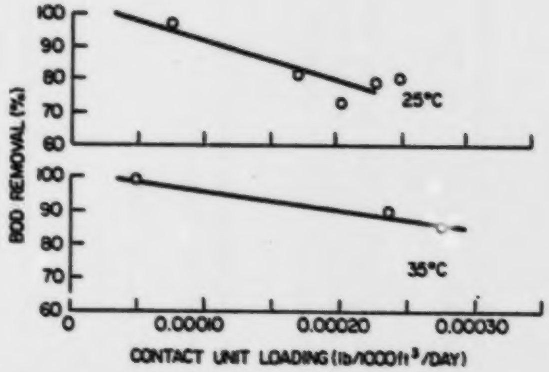


Figure 57 - Effect of loading on BOD removal removal in contact unit (after (954))

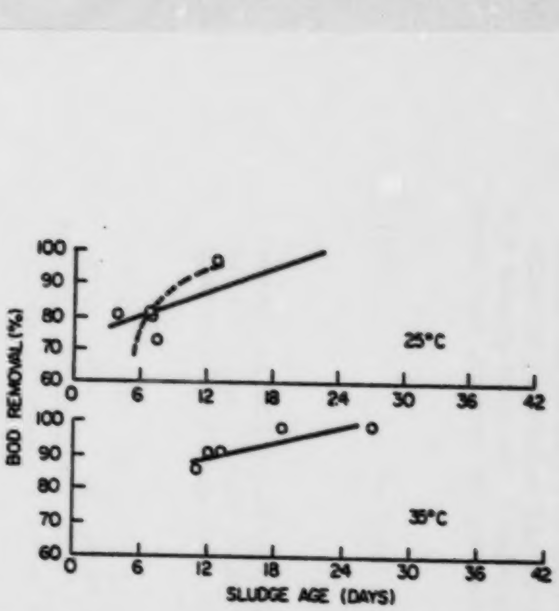


Figure 58 - Effect of sludge age on BOS removal in contact process (after (954))

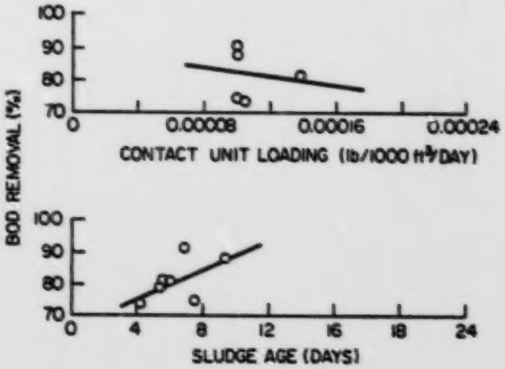


Figure 59 - Effect of BOD loading and sludge age on the performance of the rapid adsorption at 35°C (after 954))

Gas Production: The kinetic relationships of McCarthy presented earlier (Eqs. 1-10) can be extended to anaerobic gas production. Then, the cubic feet of methane produced per day, M, is a function of the yield of methane per pound of COD, M. After the form of equation [9]

$$C = (1-nY)dFXdt + nbX \qquad [9]$$

$$M = M[(1-nY)(dF/dt) + nbX] \qquad [52]$$

or

$$M = m\left[1\left(\frac{nY}{1+b\theta_c}\right)\right](dF/dt) \quad . \qquad [53]$$

As before, n = 1.42.

Buswell (198, 198a) has suggested

$$C_gH_nO_p + \ g - \frac{h}{4} - \frac{p}{2}\ H_2O\ \frac{g}{2} - \frac{h}{8} - \frac{p}{4}\ CO_2 + \ \frac{9}{2} + \frac{h}{8} - \frac{p}{4}\ CH_4 \qquad [54]$$

Temperature: The influence of temperature on the rate of BOD removal as a function of contact loading or as a function of sludge age is shown in Figure 60. The authors reported that for loadings expected to yield 90% removal, the rate of anaerobic stabilization was increased 2.5 times for packing waste but 3.5 times for milk wastes for a 10°C temperature rise. The corresponding θ values are 1.096 and 1.133 for packing plant and skim milk wastes, respectively. Data from McCarty (304a) gives a Q_{10} value of 1.71, that is a θ_T of 1.055.

A brief test in which the contact tank containing synthetic milk plant waste was allowed to vary from 35°C during the daylight hours and approached the room temperature of 24°C during the night showed a gradual breakdown of the process. In one week of operation under these conditions the BOD removal dropped from 80 to 68% and the volatile acids increased from 100 to 500 ppm. The conclusion was that this process was not tolerant to a 10°C diurnal temperature variation. Other investigators have reported similar deterioration in performance due to uncontrolled temperatures.

Sensitivity to these temperature variations may not reflect the usual change in activity for systems below their optima. Here the temperature may be suitable for different systems at 25°C and at 35°C with the sensitivity due to a lag period. A shift in relative velocities of k_1 and k_2 of Fig. 56 would also be expected. Systems reported in Schoepfer and Ziemke (954) were often operating at two to three times the critical sludge age, θ_c^m, such that a reduction in temperature would bring the system alarmingly close to washout conditions.

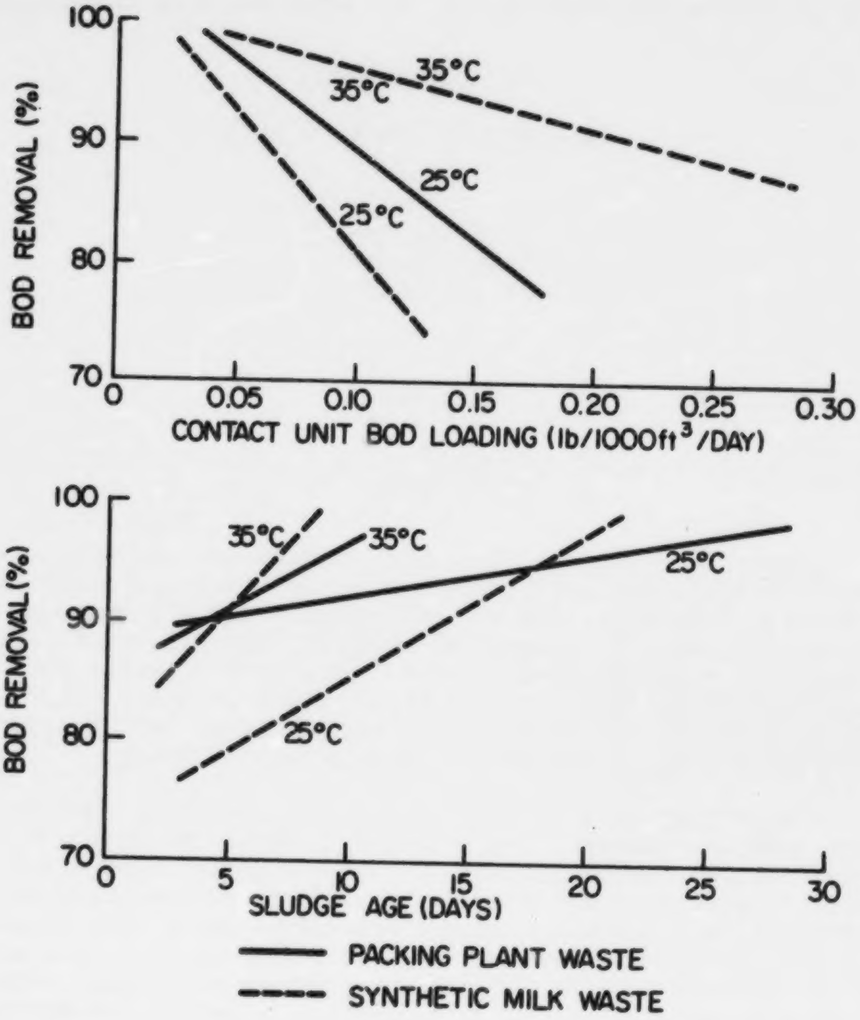


Figure 60 - Effect of temperature on BOD removal (after 952))

Schoepfer and Ziemke (954) measured gas production varying from 1 to 7 ft^3/lb of volatile matter produced compared to the 16 to 20 ft^3 of gas they expected from the conversion of organic matter. The difference was said to be a loss of gas in the evacuation system. In a closed bottle experiment where it was possible to make an accurate solid and gas balance, approximately 14 ft^3 of the gas was produced for each pound of volatile matter destroyed. The composition of the gas did not appear to vary with loading or temperature but to vary depending upon the waste used, i.e., the packing plant waste had 90% methane and 10% carbon dioxide, the synthetic milk had 85% methane and 15% carbon dioxide, and the fatty acid waste had 70% methane, 18% carbon dioxide and 12% hydrogen.

McCarty (670) has shown from theoretical considerations that approximately 5.6 ft^3 of methane gas would be expected per pound of COD reduced. This corresponds to about 17-20 ft^3 per pound of volatile solids when the gas has a methane content of about 65%.

The gas production reported in the literature (Table 88) appears to vary from about 1 to about 20 ft^3/lb.

Sludge Yield: As in aerobic fermentations the sludge accumulation would be expected to follow the relationship

$$\frac{dX}{dt} = Y(dF/dt) - \left(\frac{b}{X}\right)X \qquad [55]$$

McCarthy (670c) has suggested:

$Y = 0.054$ for amino and fatty acids, $b/X = 0.038$

$Y = 0.46$ for carbohydrates, $b/X = 0.088$

$Y = 0.076$ for nutrient broth, $b/X = 0.014$

for COD basis and $Y = 0.10$ to 0.20 for carbohydrates and 0.02 to 0.06 for proteins and fatty acids (607b) on a BOD basis.

Neither yield nor respiration rate constants, $k_r = (b/X)$, appear to be available for dairy wastes. In fact, most systems appeared to operate without sludge buildup (690). However, here, as in activated sludge experiment of the same period, sludge settling problems often led to unintentional solids discharge, Figure 61.

Dairy wastes, which are high in carbohydrate would be expected to have yields as high as 0.4 to 0.5.

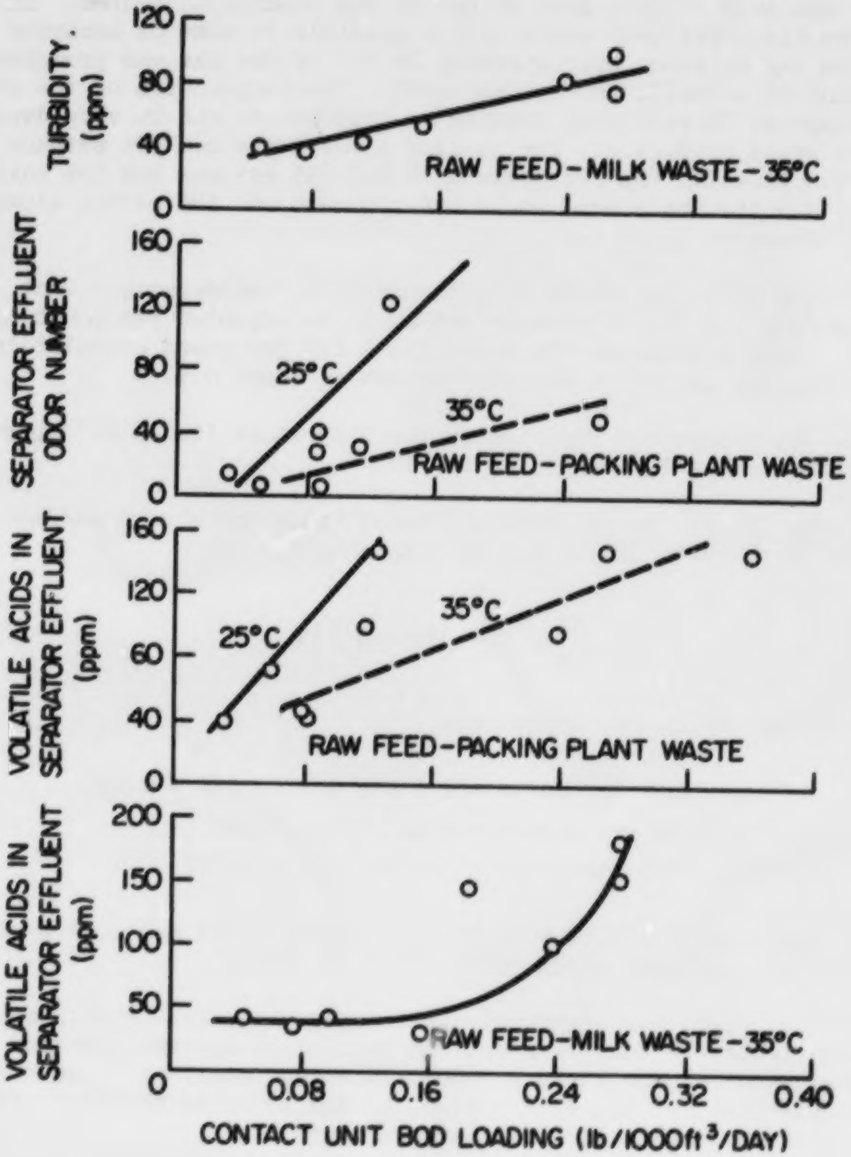


Figure 61 - Effect of BOD loading on odor, turbidity, and volatile acids in treated effluent from contact unit (after 954))

Sludge Settling: Scatter diagrams showing the influence of suspended solids applied (lb/day, ft^2) and raw flow surface settling rate and total flow surface settling rate (GPD/ft^2) upon sludge depth are shown in Figure 62. (Average data for each series are shown in Figure 63.) These data were for treatment of synthetic milk waste at a relatively low loading of 70 lb/day, 1000 ft^3 and a temperature of 25°C.

Figures 62-64 show a definite trend between higher suspended solids application rate and settled sludge depth. The scatter in the relationship between surface settling rates and sludge depth was reduced by arbitrarily grouping the data into regions of equal contact tank suspended solids. For high contact tanks suspended solids concentrations, the influence of increased surface settling rates upon sludge depth is much more pronounced than at lower contact tank suspended solids concentration. These performance characteristics also include the scatter associated with the widely varying sludge indexes found in the pilot plant study.

As would be expected, the data in Figure 63 show that under equal loading conditions the sludge depth is greater for a higher sludge volume index.

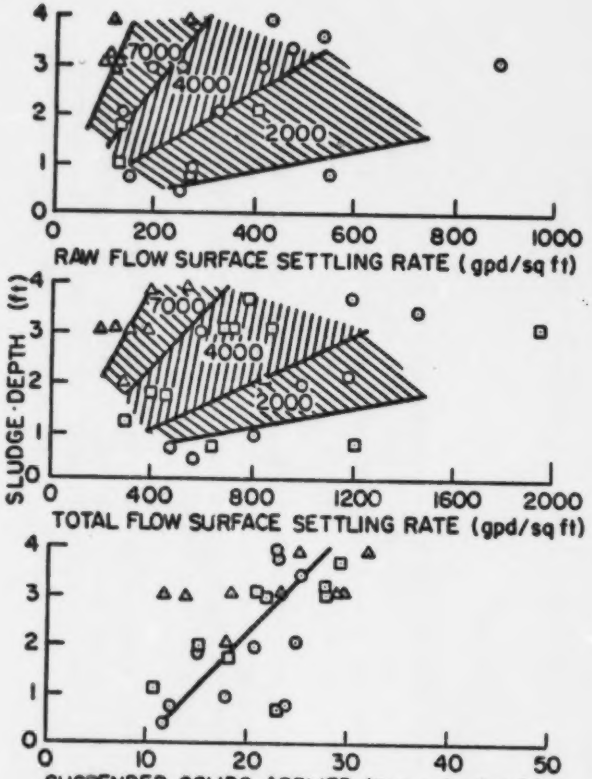
Analysis of the average data for packing plant wastes and milk plant wastes at 30.25°C and at 35°C suggested that the sludge depth found for the particular separator loading is materially affected by the character of the sludge as measured by the sludge volume index. Further, the character of the sludge, with respect to the separation and concentration, was suggested to be sensitive to a number of operating conditions including the type of raw feed and the contact loading. Further work on a particular waste at the operating conditions planned was suggested.

Literature Experiences

Cases have been reported (138, 139) where, as an emergency measure, large volumes of condensed milk and undiluted skim milk have been discharged to digesters treating sewage sludge with no permanent deleterious effect on the performance of the digesters.

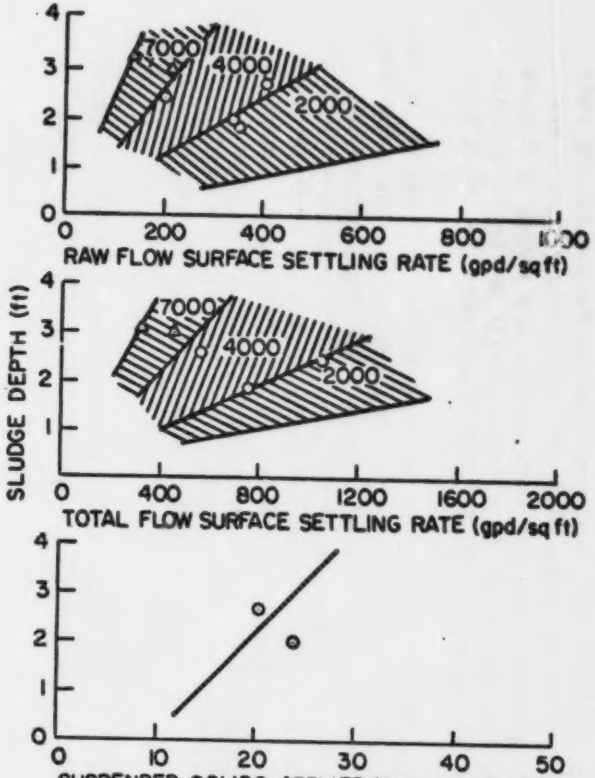
Bowles (189b) reports 60-65% reduction of organic matter and a nonputrid effluent when creamery wastes containing less 1000 ppm were treated anaerobically for six days. A somewhat longer holding period of ten days was suggested by Trebler (1125a)

Buswell et al. (198a) studied the anaerobic digestion of whey, buttermilk whey, skim milk, and combinations of wastes in anaerobic digesters with detention times varying from 20 to 60 days. The operating data for this experiment are given in Table 88. Reductions of 5-95% in BOD's were reported.



NOTE : ○ – CONTACT TANK SUSP. COL. = 2000 ppm
□ – CONTACT TANK SUSP. COL. = 4000 ppm
△ – CONTACT TANK SUSP. COL. = 7000 ppm
SOLID SYMBOL CORRESPONDS TO A SLUDGE INDEX OF 100, OPEN SYMBOL CORRESPONDS TO A SLUDGE INDEX OF 240

Figure 62 - Effect of separator loading on total sludge depth in treatment of milk waste (after (954))



NOTE : ○ – CONTACT TANK SUSP. COL. = 2000 ppm
□ – CONTACT TANK SUSP. COL. = 4000 ppm
△ – CONTACT TANK SUSP. COL. = 7000 ppm
SOLID SYMBOL CORRESPONDS TO A SLUDGE INDEX OF 100, OPEN SYMBOL CORRESPONDS TO A SLUDGE INDEX OF 240

Figure 63 - Effect of separator loading on total sludge depth in treatment of milk waste (after (954))

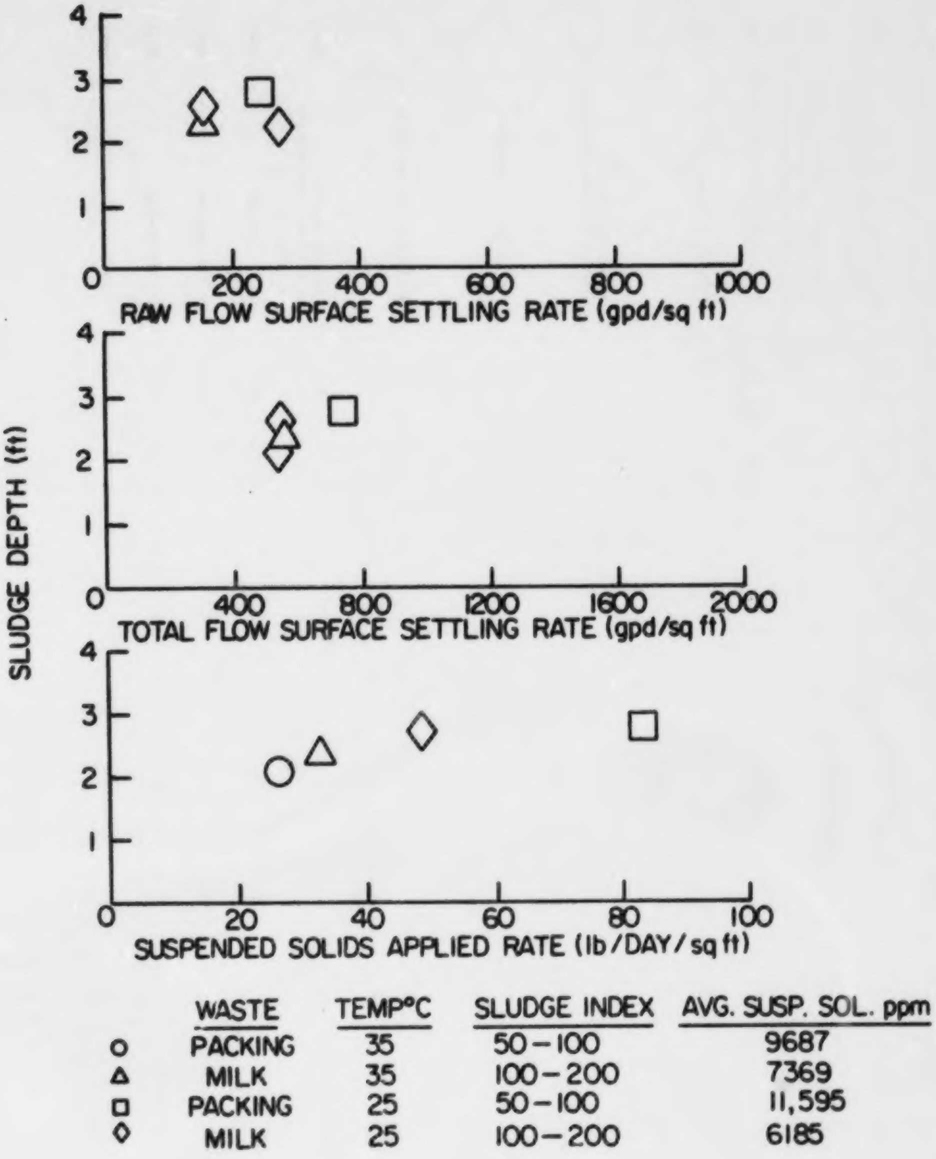


Figure 64 - Effect of separator loadings on total sludge depth (after 954))

Table 88 - Performance Data for Anaerobic Fermentation

Waste	Anaerobic Treatment Process	BOD_5 (ppm)		% BOD Reduc.	SS (ppm)		% Reduc.	pH Effluent	Digestion °C	Gas. ℓ/ℓ	Detntn (Days)	Loading g/ℓ	Remarks	Ref. No.
		Inf.	Eff.		Inf.	Eff.								
Whey		1,110	388	65	-	-	-	-	-	-	6	-	(1273)	363
Dil. whole milk	2 stage	2,200	110	95	-	-	-	-	-	-	4	-	Recirculation did not improve performance (690)	363
Dil. whole	septic	7,000	300	87	-	-	-	-	-	-	4		Dense material like asbestos required to retain sludge in digester (21-22)	363
Milk and Whey	T.F.	1,500 $KMnO_4$		70	-	-	-	-	-	-	0.08 -0.16	140 lb / 1000 ft^3,day	9.5 ft^3/lb milk solids(289)	363
Whey		35,000	-	93	62,000 (vs)	-	96.6	7.3	-	1.6	29	2.2	(150 lb TS/1000 ft^3)	198a
Buttermilk whey	Stage I	52,000	-	-	67,000 (vs)	-	95.3	7.4	-	1.9 2.4	23	2.9		"
	Stage II	-	-	-	-	-	94.6	7.5	-	0.3	-	-	Recirculation 2-4 ℓ/day, 1/3 tank capacity	"
Whey-Water 1:1	Stage I	17,500	-	85.5	31,000 (vs)	-	97.8	7.0	-	1.3	33	2.2		
	Stage II	-	-	92.2	-	-	98.2	7.3	-	0.5	-	-	Recirculation as above	"
Buttermilk whey-water 1:1:4	Stage I	17,000	-	91.8	22,000	-	96.6	7.0	-	2.7	21	3.2		"
	Stage II	-	-	94.7	-	-	96.8	7.4	-	0.7	-	-	Recirculation as above	"
Skim milk	Digester	62,000	-	91.7	100,000 (vs)	-	97	7.5	-	1.0	63	1.7		"
Evap.	F & D Digester	380	20-50	90	310 (vs)	-	55	6.4	31°		6	63	1100 mℓ gas/gm BOD strong odor reduced by aeration	1043
Evap.	F & D Digester	1,100	10-30	98	1,250 (vs)	-	89	6.4	31°		6	184	860 mℓ gas/gm BOD	1043
Evap.	F & D Digester	2,200	6-30	99.5	2,500 (vs)	-	91	6.4	31°		6	367	870 mℓ gas/gm BOD	1043
Evap.	F & D Digester	3,300	10-20	99.5	3,750 (vs)	-	93	6.4	31°		6	550	850 mℓ gas/gm BOD	1043
Creamery	Septic	< 1,000 (vs)	-	60 -65 org.	-	-	-	-	-	-	6	-	(189b)	1043

Table 88 - Continued

Waste	Anaerobic Treatment Process	BOD_5 (ppm)		% BOD Reduc.	SS (ppm)		% Reduc.	pH Effluent	Digestion °C	Gas. ℓ/ℓ	Detntn (Days)	Loading g/ℓ	Remarks	Ref. No.
		Inf.	Eff.		Inf.	Eff.								
Milk Wastes	Septic Tank	-	-	Satis.f/irr.	-	-	-	-	-	-	-	-	(821a, 620, 231)	(1040)
	Septic Tank	509	395	22.4%	-	-	-	-	-	-	-	-		
Milk Wastes	Digester	1,000	50	95%	-	-	-	-	-	-	4	-	(690)	(1040)
1% Milk	Digester	-	-	69.2	-	-	-	-	-	-	10	-	55.3% T.S. return	
Milk	Digester	-	-	65.8	-	-	-	-	-	-	10	-	T.S. reduced 67.3%	(1273)
Cheese factory wastes		3,450	1950	67	676	95	-	5.1	-	-	6	-	T.S. reduced 71% from 5429 1000 gpd capacity	(1273)
Cheese whey		35,000	-	-	-	-	-	3.5 -4.5 in/ℓ	38	-	5	$\frac{115 \text{ ft}^3}{\text{lb.org.}}$	4500 gpd	(139)
Sewage + Dairy wastes	Digester	-	-	-	-	-	-	-	-	-	-	$\frac{8.5 \text{ ft}^3 \text{ lb}}{10 \text{ vs}}$	70-80°F, gas produced 65% methane,	(661)
Milk	"Accelator"	500	-	85*	-	-	-	-	22 27	-	1	$\frac{40 \text{ lb org.}}{1000/\text{ft}^3 \text{ day}}$		954
Milk	F & D Digester 2, series	-	-	90	-	-	-	-	30	-	4		750-850 ℓ/kg	867
Milk	Digester	milk	-	> 95	-	-	-	-	-	-	25	$\frac{175 \text{ lb org.}}{1000 \text{ ft}^3\text{,day}}$		867

*COD

Table 88 - Continued

Waste	Anaerobic Treatment Process	BOD$_5$ (ppm)		% BOD Reduc.	SS (ppm)			% Reduc.	pH Effluent	Digestion °C	Gas. l/l	Detention (Days)		Loading			Ref.No.
		Inf.	Eff.		Inf.	Contact	Eff.					Raw	Total	lb/1000 ft^3,day Contact	Total	Sludge Age,days	
Skim milk + Buffer	Contact	-	-	100	-	4,918	-	-13	-	26.5	-	.347	.085	19.2	21.9	24.7	954
		-	-	97.2	-	5,016	-	54.6	-	24.0	-	.342	.076	37.1	25.7	13.0	
		-	-	81.7	-	6,120	-	- 2.1	-	23.1	-	.116	.053	84.9	58.8	6.92	
		-	-	80.5	-	5,372	-	17.7	-	21.7	-	.094	.067	123.	85.6	4.021	
		-	-	73.2		8,505	-	37.3	-	24.0	-	.388	.204	103.7	73.	7.60	
		-	-	79.4	-	8,845	-	-134	-	21.0	-	.144	.075	115.4	80.1	7.18	
Skim milk + Buffer	Contact	-	-	99.1	-	4,061	-	51.2	-	34.1	-	.300	.085	48	31	8.85	954
		-	-	97.8	-	4,208	-	41.9	-	34.0	-	.280	.083	73	45	6.16	
		-	-	91.1	-	5,687	-	48.6	-	34.7	-	.140	.037	151	93	4.03	
		-	-	91.5	-	10,002	-	58.4	-	36.0	-	.300	.115	237	145	4.34	
		-	-	86.0	-	10,134	-	57.1	-	35.7	-	.306	.114	276	169	3.76	
Skim milk + Buffer	Rapid Absorption	-	-	91.2	-	7,175	-	-	-	33.7	-	.238		100	65	6.89	954
		-	-	81.3	-	7,912	-	-	-	34.5	-	.307		138	88	5.61	
		-	-	78.8	-	8,143	-	-	-	34.1	-	.318		157	94	5.41	
		-	-	75.0	-	7,245	-	-	-	33.5	-	.354		103	65	7.5	
		-	-	88.1	-	9,216	-	-	-	34.5	-	.252		101	58	9.4	
		-	-	81.0	-	6,658	-	-	-	34.6	-	.536		119	70	6.0	
		-	-	74.1	-	4,971	-	-	-	34.4	-	.666		105	66	4.2	

Woolings (1273) surveyed the waste problem in respect to the needs of Ontario, Canada. He remarked that the most practical method, particularly for small milk plants in 1955, was still anaerobic digestion in septic tanks. These milk plants would produce approximately 1000 gal/day. Such a unit would require extremely good segregation of waste and housekeeping with no intentional discharge of skim milk, buttermilk, whey or spoiled products. Domestic sewage, broiler blow-off and hot water should be discharged directly to the digestion tank. A six-day holding time was recommended. He reported that only a 65% reduction in BOD could be obtained with a whey material having about 11,000 parts per million BOD when held for six days.

Meinck et al. (690) studied a digestion system which had ten days retention. For this system reduction in BOD and permanganate demands of 95% were achieved. They found they could reduce retention time to four days without appreciably affecting results. Recirculation of effluent was of no particular advantage. No detectable sludge accumulation was found in the first seven months of plant operation.

The experiments of Spaulding (1403) were conducted in digestion tanks of 3-liter capacity operated at 31°C. These tanks were equipped stirring mechanisms and gas and liquid withdrawal tubes. The tanks were fed daily by allowing the digester to settle one hour, removing of supernatant and an addition of evaporated milk and water to provide the desired loading. Loadings ranging from 380-3300 ppm were used to simulate the range of concentrations expected with dairy wastes. Removals of up to 99% were reported.

Reinhold, F. (867) conducted laboratory experiments in the anaerobic digestion of milk. The experiments were carried out in flasks in an incubator at 30°C. The mixture was seeded with sewage sludge, then fed daily. Ninety percent reduction in BOD and permanganate demand were reported. The gas yield amounted to 750-850 liters per kilogram of dry organic matter. The period of digestion was said to be about four days; approximately 85% of the organic matter was decomposed. The rate of digestion was more rapid immediately following the addition of fresh material. The loading was gradually increased to enable the bacteria to deal with shocks. Maintenance of even temperatures and regular additions of waste, the maintenance of anaerobic waste before treatment, an addition of asbestos flocks or similar material, and the mixing of the digestion chamber contents are all recommended.

Schroepfer and Ziemke (954) studied the application of the anaerobic contact process to packing plant wastes, fatty acid wastes, wood fiber wastes, and synthetic milk wastes. The pilot plant consisted of an agitated anaerobic fermentation vessel with continuous speed pumps, level control, vacuum degassing, level control on sedimentation, and sedimentation followed by effluent discharge and sludge return. The gas produced by the unit was trapped in a water seal device. The synthetic milk wastes fed to the column consisted of dried milk solids of various concentrations with added sodium bicarbonate to provide approximately

500 ppm alkalinity. The dry solids had an analysis of 97% solids, 83% total volatile solids, 9% suspended solids, 4% nitrogen, 78% BOD, and 98% COD.

The seed material was activating sludge from an actively operating sludge digester tank at a municipal sewage treatment plant. The sludge was first washed for several days in dichlorinated tap water, then fed low loadings of 0.01-0.2 pounds/day/ft^3 for one to three weeks.

Schroepfer and Ziemke (954) also investigated the operational characteristics of a rapid adsorption-sludge regeneration process. In this process the skim milk waste was extracted from the bottom of the agitated anaerobic vessel, mixed anaerobically, degassed, and then separated by sedimentation, with the effluent going to the sewer and the sludge returning to the anaerobic digestion unit. In this system the adsorption and digestion processes are physically separated and only the sludge with adsorbed waste needed to be reheated in the digestion vessel.

Schroepfer and Ziemke (954) reported the successful treatment of loads from 0.05 to 0.28 pound BOD/ft^3 with reductions of BOD from 86 to over 99% at 35°C, with withholding time slightly less than one to about three days. Reductions of about 80% to nearly 100% were achieved at loadings of 20 to 120 pounds BOD/1000 ft^3/day with retention times of 0.1 to 0.7 for liquor and 7 to 25 days for sludge. A second series of experiments were run at 25°C with somewhat poorer results.

Schroepfer and Ziemke (954) made an economic analysis of both the anaerobic contact process and the rapid adsorption process. For the anaerobic contact process there was a distinct advantage in maintaining higher suspended solids concentrations. The authors recommend suspended solids concentrations of between 10,000 and 15,000 as being economical for their conditions. The cost was also substantially reduced as the temperature waste approached operating conditions. This energy cost is decreased for dairy wastes which are often reported to be in the vicinity of 30°C.

The analysis of thermal requirements of the rapid adsorption process showed a distinct advantage in operating with higher raw sewage temperatures and substantially reduced heat requirements as the percentage of return sludge was reduced. However, the reduction and return sludge volume also lengthen the contact period and reduced the temperature during the contact process. The advantage of this process is said to be reduced as the waste temperatures approach the operation temperature and when the concentrations are low.

Dewes (289) has reported that an upward-flow anaerobic biological filter gave a 70% reduction of BOD in a milk-whey waste with a $KMnO_4$ concentration of 15,000 parts per million with a two-four hours retention time. Subsequent lime coagulation using 120 parts per million increased the reduction to 90%. The corresponding BOD reduction was 80-85%.

Young and McCarty (1283) suggested such a filter, applied in two stages, for milk plant wastes. However, they report channeling, very poor adaptation to waste or loads, and sulphide odors for a "carbohydrate-protein" waste. Sludge build-up may also be a problem with this particular approach.

Svoboda and Co-workers (1085) have independently evaluated the system of Pien for fermentative disintegration of dairy effluents. In this process the waste from dairy plants at times containing whey is treated aerobically for 24 hours to reduce the lactose content. At this time the waste has a pH of 6.5 to 6.8. This process is continued for 24 hours, then the sludge is digested at temperatures of 37 to 40°C with a pH of 7.5 to 8 for 24 hours. On the third day the effluent is aerated for four hours, then a flocculating agent such as $FeSO_4$ or $Al_2(SO_4)_3$ or a superphosphate with dosages of 1 kg/m^3. Lime is added until a pH value of 8 to 8.5 is reached. The sludge is then coagulated and separated by sedimentation. In their studies the effluent went from the digester to an equalization pit and then to the river. The sludge, estimated to be about 10-20% of that originally formed was then filtered through beds of peat using 1 $m^3/1\text{-}2m^2$ sludge. After one day sludge deposited on the peat bed is removed to be used as compost.

Experiments in 1954 and 1955 showed a 100% degradation of lactose a minimum 50% conversion of total nitrogen to soluble nitrogen. Wastes containing 8 to 30% whey had BOD reductions of more than 90%.

This approach reduces the C/N ratio which may be desirable for whey or buttermilk wastes, for it may well lead to reduced volatile acid levels and increased activity of methane producing organisms. Here settling problems for the aerobic sludge is of no real concern.

Performance Data

Available literature performance data for anaerobic treatment systems are summarized in Table 88.

Operational Problems

The operational problems suggested by the very few reports of experiences with dairy wastes appear to be

(1) The development of pH values below the range of 6.6 to 7.6 desired by the methane organisms.

(2) Strong effluent odors

(3) Poor sludge settling characteristics

(4) Very high temperature sensitivity

(5) Digester mixing problems

(6) Toxicity of materials in the dairy plant effluents.

In the first experiments of Spaulding (1043) the effluent had a pH of 7, a volatile acid content of 200. After four weeks, the pH had decreased to 6.4 and the volatile acid decreased to less than 100 ppm. The pH could be raised by aeration. The detention time of six days (as compared to shorter times) was said responsible for pH values to drop further with accompanying volatile acid accumulation. Similar improvement would be expected for large sludge ages and for greater sludge return ratios. Figure 63 indicates reduced design loadings as another means of preventing pH inhibition of methane producing organisms. (In fact, Buswell et al. (198a)) in lab studies controlled feed rate, an option not available to a waste treatment plant). Feed control rate from an aeration holding tank help even out volatile acid levels.

Steffan (1055) reports that Schroepfer experienced failure of the fermentation on one occasion, which was corrected by the addition of sodium bicarbonate to give 500 ppm alkalinity. This practice was continued in the experiments reported later (954).

Calcium carbonate might be used for pH control if it were not for the calcium sensitivity of the milk proteins, or the danger of $CaCO_3$ precipitation if used to excess.

Spaulding (1043) reported that the effluent had a disagreeable odor which could be dispelled by aeration. This aeration did not influence the volatile solids content but did reduce the BOD effluent 10-15 ppm (50%). Figure 61 shows that for meat packing wastes this odor is lower at 35° than at 25°C fermentation temperatures. Degassification generally helps.

Schroepfer and Ziemke (954) attempted to demonstrate the effect of degassification on the separation performance. The tests were confounded by poor sludge characteristics and occasionally by the occurrence of floating sludge. In general, the observations indicated that at low contact loadings positive separation could be achieved without degassification. At higher contact loadings gas activity was generally high and degassification was found necessary to prevent extensive gas lifting and loss of protein solids.

The poor sludge settling characteristics might also have been due to mixing effects. Mixing rates were said to be a compromise, for if mixing were not provided the sludge separated into a heavy floating layer, a relatively dilute internatant layer and a heavy settle layer. At very high mixing rates (in the digester or degassifier) the sludge floc breaks up into fine particles which appear to re-form in a matter of a few minutes after the mixing is stopped. Further, they reported that some mixing is important to achieve intimate contact between the substrate and the active sludge (954).

Spaulding (1043) reported that the stirring mechanism interfered with sludge settling. Occasional drawing off of part of the sludge was said to be a satisfactory solution. (Temporary loss of effluency could also be expected, however).

Schroepfer and Ziemke (954) suggested that "further work is necessary to determine the specific factors which affect the concentrating ability and bulking characteristics of anaerobic sludges."

Trebler and Harding (1137) reported best results at temperatures of 90-95°F with sufficient agitation to prevent solid scum layer formation. Under these conditions they effected 50% BOD reduction in 3 days; 80% reduction in 10 days. An overloaded septic tank becomes acid, ineffective, and difficult to restore to proper operating conditions.

Harding and Trebler (429) noted that performance of sludge digesters has generally not been satisfactory even when the capacity is ample, on the basis of the usual city waste assigned figures. They commented that the difficulty is associated with the accumulation of scum and sludge volumes and it is necessary to provide for both temperature control and agitation. When these precautions are taken they expected satisfactory performance.

Malina and Miholitis (651a) have discussed current temperature control and mixing approaches. A number of approaches are suitable. Discussion of these proprietory approaches is beyond the scope of this report.

Andrews (25b) has stressed that nonuniform mixing or nonuniform feed rates can result in the buildup of amino acids, the development of low pH, or NH_3 buildup which inhibit complete treatment of the waste. Amonia nitrogen, NH_4, in the buttermilk and whey fed, and the buildup of toxic nitrogen-containing decomposition products were each said to be probable explanations for the treatment efficiencies for diluted (1:1 or 1:2) being better than for undiluted whey or whey-buttermilk wastes.

The ion concentrations may at times be sufficient to inhibit anaerobic fermentation. The ion which first comes to mind is Na^+. This Na^+ comes from product loss, cleaning compounds and water softening. Boiler compound and condenser descaling materials are other potential sources of toxic materials. Information on the ionic composition of waste does not appear sufficient to assess the inhibition possibilities at this time.

White (1242) has suggested that butter fat be kept out of anaerobic fermenters. However, Anderson et al. (22) found fat could be metabolized in a septic tank, but breakdown rates are said to be slow. At low residence times free fat could readily pass through a digester relatively untreated.

LAGOONS

In the dairy industry, lagoons have been used primarily to treat the high strength waste from small cheese factories and condensing and drying plants, or to provide additional treatment for the effluent from an activated sludge or trickling filter system. These systems usually are in rural areas where land costs are low, and where the system can be some distance from neighbors.

These lagoons may be of four types: (a) aerated, (b) aerobic, (c) facultative or aerobic-anaerobic, and (d) anaerobic. Some design characteristics for these lagoons as compiled by Eckenfelder (312a) are shown in Table 89. The biological processes in lagoons may include aerobic oxidation and growth of aerobic bacteria, growth and photosynthesis of algae, anaerobic oxidation and growth of methane producing bacteria. All of these processes depend upon the oxygen level and sunlight intensity. In general, increasing the depth and/or increasing the loading will shift a lagoon from aerobic to facultative and finally to anaerobic conditions. Climate conditions also have a major influence on the maximum loading for a lagoon type. For example, satisfactory loadings for an anerobic lagoon appear to be over 200 lb/acre-day in Alexandria, UAR (343), about 50 lb/acre-day in the South and Southwest, USA (1097a) or about 10 lb/acre-day in areas of the United States and Canada which have winter ice cover (838a). The limiting operational problems also vary. In the first two examples, the major problem appears to be algal growth and economics, while in the later example the major problem appears to be the odor problem during the period of ice breakup with the algal problem is secondary.

Table 89 - Design Characteristics for Lagoons
(779a, 670) (after 312a)

	Aerobic	Facultative	Anaerobic	Aerated
Depth, ft.	0.6-1.0	2-5	8-10	6-15
Detention, days	2-6	7-30	30-50	2-10
BOD loading, lb/(acre)(day)	100-200	20-50	300-500	
Percent BOD removal	80-95	75-85	50-70	55-90
Algae concentration mg/liter	> 100	10-50	nil	nil

Lagoon Design Approaches: The design of lagoons for dairy waste treatment has been largely empirical and often, as indicated in the surveys of Carl (210) and Porges (838), many operational characteristics have not been available. Design approaches based on stoichiometric and kinetic principles are relatively recent developments.

The design of aerated lagoons has been shown to require the same basic kinetic data and stoichiometric relationships for biomass production and oxygen requirements needed for design for activated sludge treatment (312a, 314, 654c). However, the loadings are on the order of 1 to 15 lb BOD/1000 ft^3 (200 to 3,000 lb/acre-day) as compared to about 8 to 15 lb BOD/1000 ft^3 day for extended aeration and more than 15 lb BOD/1000 ft^3 day for activated sludge (1097a). Since the aerated lagoon generally is influenced by environmental temperatures more than is activated sludge, temperature receives more emphasis in design. As a first approximation the kinetic yield and respiration data presented earlier may be used in the design of an aerated lagoon for milk wastes. The experiments of Wuhrmann (1278b) for activated sludge suggest greater gross sludge yields, and significantly reduced sludge respiration under conditions of low sludge load or moderate-to-high sludge age.

An investigation of aerated lagoon treatment of cheese plant wastes, including some whey, is in progress. This demonstration project may provide useful performance data.

Ultimately a laboratory-pilot plant study like that of Mancini and Barnhart (654c) will be required to determine (a) an appropriate kinetic relationship and rate constants, (b) sludge and oxygen yield coefficients, (c) sludge respiration rates and yield, (d) operating data for toxicity and temperature effects, and (e) perhaps sludge settling characteristics.

Pipes (815) followed the change in pH and BOD removal for a synthetic milk based waste in quite shallow, lab scale, aerobic lagoons, and provided BOD removal vs. residence time information.

Very recently El-Sharkaw and Moawad (343) have developed and evaluated a promising approach for modeling the interrelationships of aerobic bacteria and algae during aerobic lagoon stabilization of milk waste in the UAR. Additional confirmation and data for milk wastes under various U.S. sunlight and temperature conditions are necessary.

Rich (877a) has made an integrated presentation of a method of designing aerobic lagoons developed by Oswald and co-workers (779b-f). Here, the hypothesis is that the percentage of incident solar energy which is used for algal synthesis is proportional to the oxygen produced, and that this is the sole source of oxygen utilized in the removal of the ultimate BOD. From this relationship and this BOD load the area sufficient to supply this solar energy may be computed. The retention time and pond depth for this area is then computed using the assumption that the BOD removal follows first order kinetics as it might in a BOD bottle test. (Such kinetic data are presented earlier in this report.)

In another text, Fair et al. (350) have treated a somewhat similar approach developed by Herman and Gloyna (448a). In this approach the detention time was said to be proportional to the waste concentration.

Retardant, i.e., second order with respect to L and nearly constant BOD levels as in equation (26), kinetics have also been applied to describe waste degradation histories (402, 654). Kinetic data are not available for this approach for milk systems.

Gloyna (402) has noted three additional possible bases for design of an aerobic pond for milk waste treatment: (a) a minimum depth with maximum algal production (779c), (b) maximum algal production considering total BOD design load (124a), and (c) induced mixing which may support increased aerobic bacterial activity (314d). Others (522, 855) have used aerobic ponds. Design approaches for these complex systems were not given.

Oswald (779a) has suggested that assurance of an anaerobic condition is necessary for facultative as well as for anaerobic lagoons. For fall conditions in California, essentially the whole lagoon was shown to be anaerobic for loadings in excess of 200 lbs/acre-day, and facultative for depths of greater than 0.6, 1.7, 3.6, and 6.5 feet for loadings of 150, 100, 50 and 25 lb/BOD-acre-day, respectively. The use of lagoon bottom contouring to form a digestion chamber for bottom sediments was also suggested.

According to Gloyna (402), Marais (657c) has suggested that the fraction of soluble BOD in the influent and the soluble fraction of BOD products from the sludge BOD fraction be considered the initial BOD load. However, both waste loads were presumed to have the same retardant kinetics and rate constant. Gloyna suggested a weighted average of the soluble BOD and ultimate sludge BOD load and rate constants be used as an interim estimation procedure.

The next step in refinement of the design procedure appears to be the extention of the kinetic approaches to the three interacting zones, the solids, the anaerobic fluid layer, and the aerobic surface layer.

In this report primary attention will be given to those studies in which dairy waste was treated, and to those approaches which can be used to interpret or extend the available information on dairy waste.

Aerated Lagoon: In the past, lagoons were often aerated when natural surface aeration proved inadequate for the operational loads. More recently, lagoons have been intentionally designed because of their potentially high-loading capacity.

Mancini and Barnhart (654c) reported the following advantages and disadvantages for aerated lagoon systems.

Advantages:

1. Relatively low operating and capital costs.
2. Low operating skill requirements.
3. High-quality effluent obtained with solids separation.
4. At low loading rates, biological solids are relatively stable (an advantage?).
5. Resistance to upsets.
6. Ability to treat high strength wastes.
7. Buffering capacity when pH is a problem.
8. Relatively large heat transfer when high temperature wastes are to be treated.

Disadvantages:

1. Effluent quality without solids separation is on the order of hundreds of mg/ℓ.
2. At high loadings solids separation is possibly a significant problem.
3. System is temperature dependent with reductions in removal at low temperatures.
4. Land area climates normally are much greater than those for activated sludge systems.
5. Once upset by toxicity, the lagoon possibly requires extended operating periods for complete recovery.

A possible interim design procedure for aerated lagoons is outlined below:

(1) Assume a lagoon fluid temperature

(2) Assume an effluent soluble BOD concentration, L_e

(3) Assume a detention time

(4) Select a suitable kinetic model, flow model and rate constant (using the data from Table 65, and Table 66, and equations [12], [12a], or [15a]. The rate of BOD removal during an unseeded BOD test is an estimate of the lowest rate to be expected. k values at several dilutions will help pick up possible toxicity effects of other materials in the wash.

(5) Correct the rate constant for temperature. (Procedures are discussed later.)

(6) Calculate an equilibrium microbiol solids level, X_e, using a relationship like equation [51] below. This was developed based on a materials balance in a well-mixed lagoon (654c).

$$X_e = \frac{Z + a\,(L_o - L_e)}{1 + bt} \qquad [56]$$

where

Z = influent solids

a = yield factor of solids from BOD load (L_o-L_e) as in equation [15b].

b = fraction of the solids degraded, day^{-1}

(7) Calculate the filtered effluent BOD from the kinetic equation. In example given by Mancini and Barnhart (654c) this would be

$$L_e = \frac{L_o - Z\,X_e \cdot t}{KX_a t + 1} \qquad [57a]$$

from

$$\frac{L_o - L_e}{X_e t} = K_2 L_e \qquad [57b]$$

Compare the assumed and calculated solids, and return to step (2) with the new estimated solids concentration if the difference is too large.

(8) Estimate the BOD of the effluent, L_T stream from the relationship

$$L_T = L_e + n'X_e \qquad [58]$$

where n' is the fraction BOD in the suspended solids. The data of Mancini and Barnhart (654c) for "a soluble waste" may be approximated by the relationship

$$N' = 0.38(\theta_c/24)^{-0.08} \qquad [59]$$

where θ_c is the sludge age, (or residence time, t, for a flow-through system. Similar data are needed for dairy wastes. Note also that n' is on the order of 0.25 to 0.4 compared to n' values of 0.84 for the degradable fraction of sludge (after McCarty and Broderson (670e)), and n' values of about 1.2 to 1.42 for dairy sludges reported earlier.

(9) Next, the oxygen requirements may be calculated by equation [60].

$$\frac{lbO_2}{day} = a'\ell_r + b'\mathcal{X} \qquad [60]$$

or approximately

$$\frac{lbO_2}{day} = a''\ell_r \qquad [61]$$

Eckenfelder (314) has suggested that a" is on the order of 0.9 to 1.4 wastes as compared to a' values of 0.35 to 0.48.

(10) These calculations would need to be repeated for successively longer detention times if the effluent was not sufficiently low as a plug flow system instead of a well mixed system, or successive well mixed stages would be required.

(11) This procedure should be repeated for both winter and summer conditions. Greater depth may be required during the winter if aeration devices will permit.

(12) Suitable aeration devices should then be selected on the basis of performance data.

Aerobic Lagoons: Pipes (815) has studied the pH variation and BOD removal of dextrose-beef extract-tryptone based synthetic sewage media and milk solids-urea based synthetic sewage in laboratory scale stabilization ponds under artificial light.

The laboratory scale model stabilization ponds were white enamel pans 19 x 11 x 3 inches, a depth like that in ridge- and furrow-irrigation. The composition of the synthetic sewage media is shown in Table 90.

Loading levels on the pond are not stated explicitly. If the waste strength was maintained constant at 161 ppm and the volume of feed varied to give retention times of 5, 10, 20, and 3 days used in the experiment, then the corresponding loading levels were 2.4, 1.2, 0.6, and 0.4 lb/acre. The corresponding loadings in pounds of BOD/1000 ft^3 are 0.20, 0.10, 0.05 and 0.03. These simulated ponds were found to reach an equilibrium condition within 30 to 40 days. At this point data reported in the paper were collected over one full operating day.

At a lighting intensity of 1000 footcandles (and/or "simulated" dairy waste at/or 600 footcandles for media A), the BOD reduction decreased the detention period for effluents with pH of below 7.5 and increased the detention period for effluents with pH 8.0, as shown in Figures 65-66.

Table 90 - Composition of Synthetic Sewage Media Used by Pipes (815)

Component	Conc. (mg/ℓ)	
	Medium A	Medium B
Dextrose (Difco)	180	--
Beef extract (Difco)	60	--
Tryptone (Difco)	125	--
Milk solids	--	200
Urea	--	20
KH_2PO_4	6.8	6.8
K_2HPO_4	8.7	8.7
$KHCO_3$	150	250
$MgSO_4$	5.0	5.0
EDTA	5.0	5.0
Micronutrients:		
Fe	0.5	0.5
Ca	0.5	0.5
Zn	0.5	0.5
Mn	0.1	0.1
Cu	0.1	0.1
Co	0.1	0.1
Mo	0.1	0.1
B	1.0	1.0
BOD	222	161

Curve B of Figure 65 is (1) similar in shape to those expected for simple kinetic models such as a fractional order reaction, the Monoad model, or the retardant reaction, and (2) like the illustration chosen by Eckenfelder (412a) to illustrate aerobic pond performance, and (3) like that for cannery wastes (17a). Curve A may be caused by mechanisms such as reduced sludge enzyme activity with increased sludge age as discussed earlier, or a pH or alkalinity associated reduction in activity; for the tabulated data indicated that the maximum daily pH tended to decrease for longer detention times for high pH influent and conversely for low pH influents. Similar results have been obtained in batch studies of cannery wastes (17a). Crossing of curves A and B was also noted at long detention times.

Figure 66 shows the influence of pH on BOD reduction for short detention periods (high loading) and long detention periods (low loading). The effect of reduced pH caused by lower influent pH's seems to be significantly reduced for the longer detention periods of 20 days more often encountered with stabilization ponds of dairy or dairy and municipal wastes.

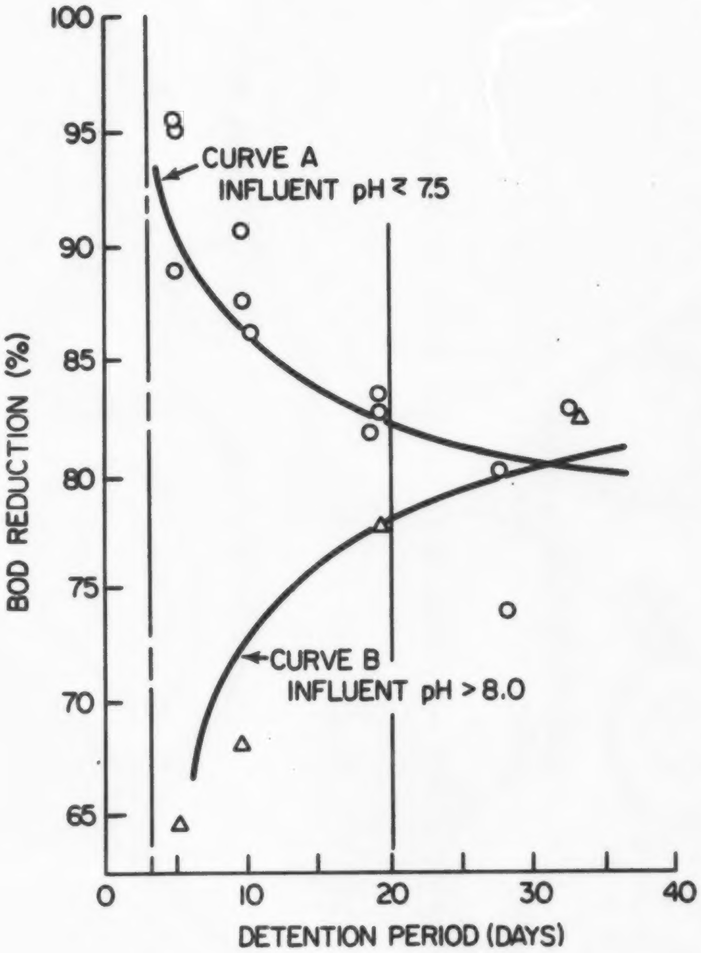


Figure 65 - BOD reduction as a function of detention period and influent pH (light intensity = 1,000 footcandles) (after Pipes (815))

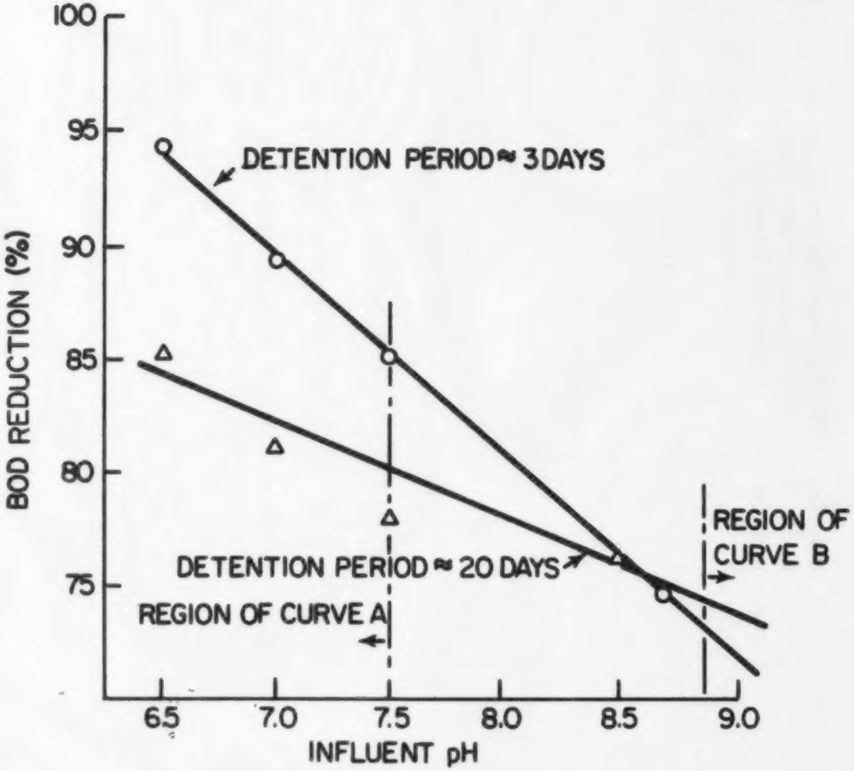


Figure 66 - BOD reduction as a function of influent pH and detention period (light intensity = 1,600 footcandles) (after Pipes (815))

The BOD reduction data for 1600 and 600 footcandles do not appear to be significantly different as would be expected from reports (402, 877a) that the saturation intensity is 600 footcandles for Chlorella species. According to equation [62] the fraction of energy utilized is 0.905 and 0.743 for 1000 and 1600 footcandles, respectively, to give incident utilizable light intensities of 905 and 1200 footcandles, respectively.

$$f = \frac{I_s}{I_o}\left(\ln\frac{I_o}{I_s} + 1\right) \qquad [62]$$

where

f = fraction of available light utilizable

I_o = incident light intensity

I_s = saturation light intensity (779e)

On the basis of experiments with the beef dextrose tryptone media (Media A) he concluded that loading a stabilization pond during the daylight hours did not appear to be a practical method of decreasing maximum daytime pH and that lowering the pH of the influent does not prevent the rapid increase of pH during the daytime but does reduce the maximum obtained. The influence of pH on BOD removal efficiency was said to be important only on the high-rate type stabilization ponds and not on the conventional-type stabilization ponds.

El-Baroudi and Moawad (323) took note of the postulate by Marais and Shaw (657b) that the BOD removal in ponds was approximately first order reaction. They further noted the study by the same author (657a) which showed that actual measurement of BOD reduction on existing ponds did not conform well with first order kinetics. In fact, others (122) had reported effluent samples at times higher than those of the influent.

They postulated that a first order removal of BOD by bacterial population assumed a well mixed oxidation pond unit, and presumed sinusoidal algal interference.

These basic assumptions are shown in symbol form in equations [63]-[65] below.

$$\frac{dL_b}{dt} = K_1 L_b \qquad [63]$$

$$QL_o dt = QL_b dt + V\, dL_b \qquad [64]$$

$$\Delta L_a = xL_o \cdot \sin K_2 t \qquad [65]$$

where

L_b = effluent BOD as a result of bacterial action, ppm
L_o = influent BOD concentration, ppm
ΔL_a = BOD removal, ppm, by algal action
K_1 = first order rate constant for BOD reduction by bacteria, day^{-1}
K_2 = a "rate-constant" for algal BOD stabilization, day^{-1}
x = fraction of influent L_o influenced by algae
Q = flow rate through the system
V = volume of the system

The cumulative behavior of the pond is shown in Figure 67. The integrated form of the equations are shown below.

Substitution of equation [63] in equation [64] and replacement of V/Q by nominal detention time, T

$$\Delta L_B = L_o\left[1 - \frac{1}{K_1 T+1}\right] \qquad [66]$$

and by integration the mass of BOC removed at time, t, is

$$\Delta \mathcal{L}_B(t) = Qt\Delta L_B = \left[1 - \frac{1}{K_1 T+1}\right]\mathcal{L}_o(t) \qquad [67]$$

where $\mathcal{L}_o(t)$ is the mass of BOD added at time, t.

Also by integration of equation [65] the total BOD removed by algal action is

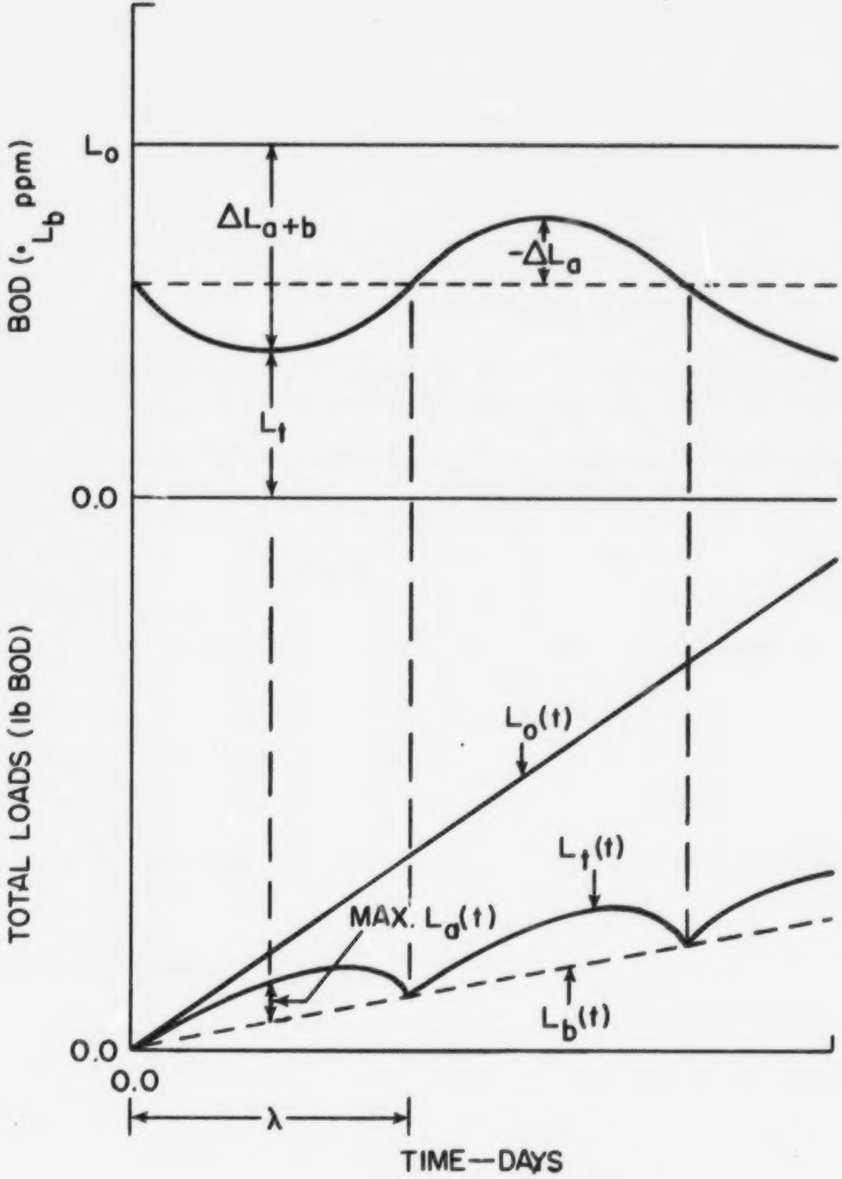
$$\Delta \mathcal{L}_A(t) = Q\int_s^t x\, L_o \sin K_2 t dt = \left(\frac{x}{K_2 t}\right)\left(1 - \cos K_2 t\right)\mathcal{L}_o(t) \qquad [68]$$

Since

$$\Delta \mathcal{L}_T = \Delta \mathcal{L}_B + \Delta \mathcal{L}_A \quad \text{also} \quad L_t = L_b - \Delta L_a \qquad [69,70]$$

then

$$L_T = L_o\left[\left(\frac{1}{K_1 T + 1}\right) - x \sin K_2 t\right] \qquad [71]$$



BOD (• L_b ppm)
L_o
ΔL_a+b
-ΔL_a
L_t
0.0
TOTAL LOADS (lb BOD)
L_o(t)
L_t(t)
MAX. L_a(t)
L_b(t)
0.0
0.0
λ
TIME—DAYS

Figure 67 - Graphical representation of proposed equations of El-Baroudi and Moawad (323)

and the total cumulative mass of BOD removed is the sum of equations [67] and [68].

$$\Delta \mathcal{L}_t(t) = \left[1 - \left(\frac{1}{K_1 T + 1}\right) + \left(\frac{x}{K_2 t}\right)\left(1 - \cos K_2 t\right)\right] \mathcal{L}_o(t) \qquad [72]$$

The values of K_2 are found from the period lambda of the algal cycle as shown in equation [73], the maximum BOD stabilized at time t for the algae is expressed in equation [74] which is obtained from the solution of equation [68].

From the definition of the sine function

$$K_2 = 2\pi/\lambda \qquad [73]$$

and

$$L_A(t)\max = 2\,\frac{\mathcal{L}_o(t)}{t} \cdot \frac{x}{K_2} \qquad [74]$$

so

$$x = \frac{\mathcal{L}_A(t)\ K_2 t}{2\mathcal{L}_o(t)} \qquad [75]$$

Table 91 shows a summary of the characteristics parameters for the various runs. Figure 68 shows their comparison of the calculated curves

Table 91 - Characteristic Parameters (after
El-Baroudi and Moawad (323))

Parameter	Run 1		Run 2		Run 3	
	Pond 1	Pond 2	Pond 1	Pond 2	Pond 1	Pond 2
Temp. range (°F)	75-92	75-92	54-70	54-70	15-77	15-77
Loading rate lb BOD/day acre	70	--	82.5	165	93	46.5
Cycle period, days	9	9	16	16	10	5
K_1, day^{-1}	0.112	--	0.057	0.043	0.334	0.005
χ	0.666	2.860	0.630	0.790	0.785	1.350
K_T	0.700	0.700	0.392	0.392	0.628	1.256

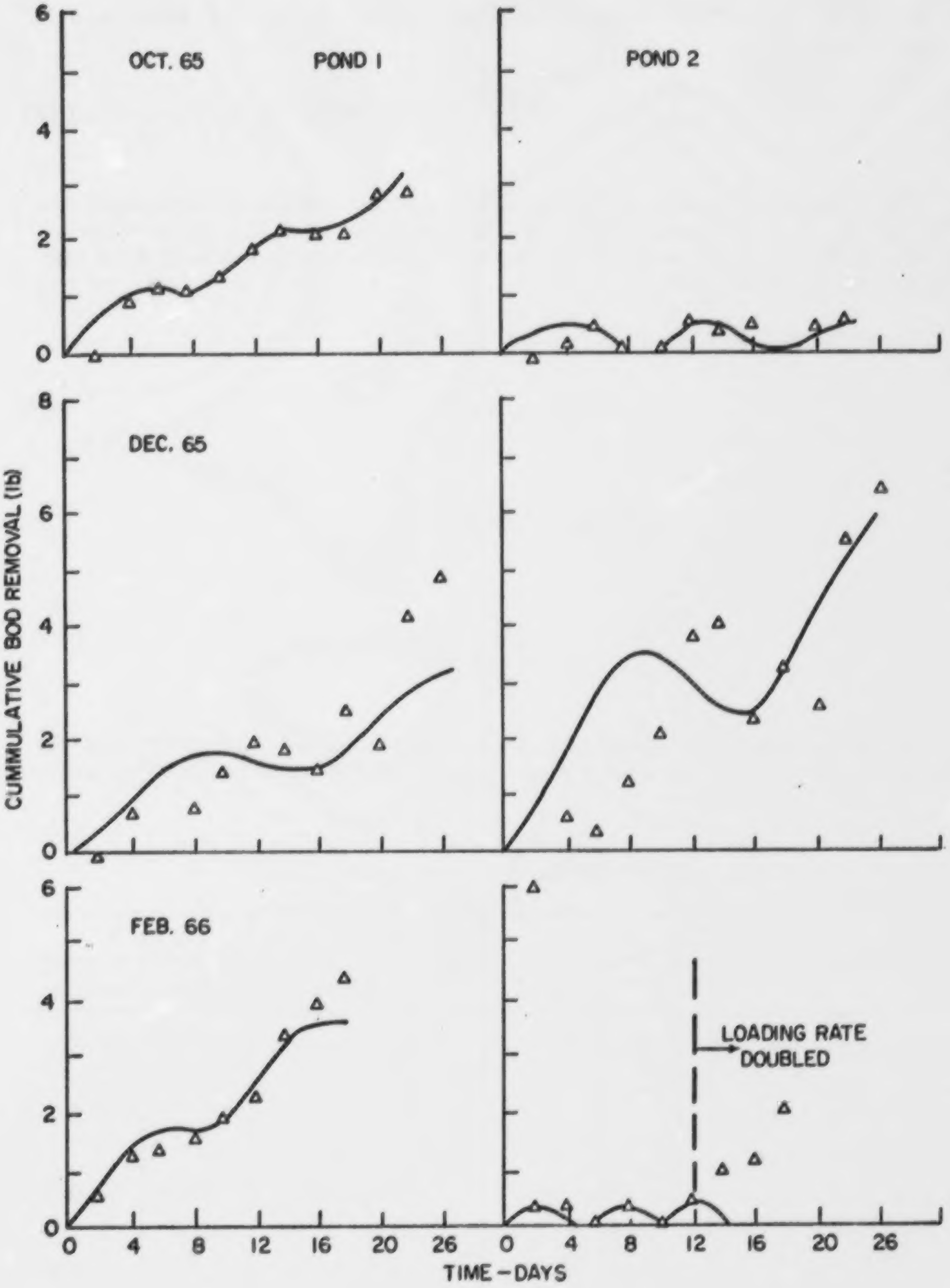


Figure 68 - Graphical comparison of calculated curves and experimental points of El-Baroudi and Moawad

with the experimental results. The values of k_1 were calculated from equation [76]

$$K_1 \approx K_T = \frac{T^{(t)}}{[\mathcal{L}_o(t) - \mathcal{L}_T(t)\ T]} \qquad [76]$$

at times equal to period T, for at those times K_T approaches K_1 as a minimum.

The best results appeared to be for Run 1 and Run 3. In Run 2 a lag between the predicted and the observed data is noticeable. This series was run during the period of lowest temperature and of lowest light intensity of the three runs. In this series, Pond 1 received an intermediate loading and Pond 2 was loaded appreciably heavier than upon other occasions. The authors suggest that this lag period is due to slow acclimatization of the flora to the substrate and will be generally less noticeable at periods of higher biological activity as indicated by higher temperatures and higher light intensities.

The authors suggested that two factors affect K_1 values; first, temperature, and second, the algae species. The influence of temperature is noticeable in a comparison of Runs 2 and 1. Here a decrease in average temperature of 12°C decreased the value of K_1 to about half its former value. However, while the temperature increase was an average of 3°C from December to February, K_1 increased six-fold the value for Pond 1. The authors suggested that the blue-green flora present in December was less efficient than the green flora found in February. The very low value of K_1 found in Pond 2 was attributed to underloading. An interpretation of K_2 was not discussed.

$$L_{max} = L_o\left(\frac{1}{KT+1} + x\right) \qquad [77]$$

Equation [77] indicates that when the value of x exceeds the fraction of the influent BOD stabilized by bacterial action an effluent BOD concentration higher than an influent will occur. Further the investigators found that the fraction x was dependent upon the loading rate as shown in Figure 71. Above loading rates of 132 lb/day-acre, the fraction x appeared independent of loading rate.

From equation [75] and Figure 69 it is evident that the maximum effluent BOD can be reduced by extending the detention time, t, or by increasing the loading rate to a high as 132 lb/acre-day for their condition. This loading rate is 6 to 13 times higher than those often found for ponds treating dairy wastes.

For a pond operating at a load of 20 lb/BOD/acre with a holding time of 30 days and a K_1 value of 0.33, the BOD effluent/BOD influent ratio would be 2.29. If the load was doubled with a corresponding

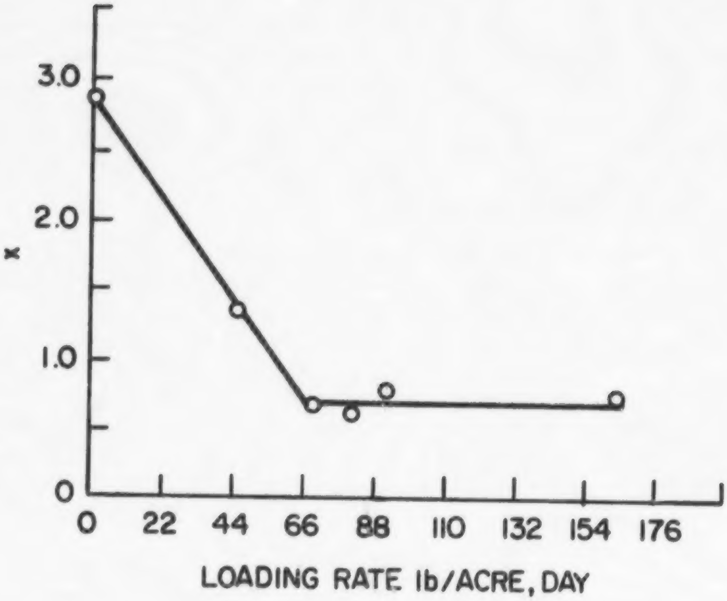


Figure 69 - Variation of x_f with loading rate

halving of the holding time, the maximum L_e/L_o ratio would be about 1.82. This estimation procedure suggests that the loading rate rather than the residence time may be much more significant in determining the maximum possible effluent BOD at low loads.

This maximum effluent BOD possibility requires provision for further treatment if the effluent is to be discharged to a water course. Instability of operation may occur when the period, $2\pi/K_2$, for a second basin in series is near that with the period of the first basin-based control stability concepts from chemical process industries.

The design procedure of Oswald (799a-e) as integrated by Rich (877a) may be applied to dairy waste systems. Consider for example an aerobic lagoon treatment system in which:

(1) The reaction rate constant k is 0.05 day^{-1} as it might well be at 20°C as indicated from BOD bottle kinetic data for milk fractions or for milk at 10°C (Tables 65, 66).

(2) The desired waste reduction is 85%.

(3) The algae has an extimated heat of combustion of 6000 cal/g, and a ratio of oxygen produced/ cell mass synthesized of 1.64, and an effective conversion efficiency of 4%.

Then the area of lagoon required is

$$A = \frac{8.56\ L_oQ}{(.85)(1-10^{-5k})S} = \frac{17.3\ LQ}{S} \qquad [78]$$

where
A = lagoon area (acres)
L_o = waste $BOD_5{}^{20}$ (ppm)
Q = waste flow (mgpd)
S = incident radiation (cal/cm^2 day).

The required residence time (T) for plug flow would be

$$T = -\log\ (1 - \text{percent reduction})/k \qquad [79]$$

$$T = 0.924/k \text{ or } 18.5 \text{ days} \qquad [80]$$

Further, since $t_o = DA/Q$ for plug flow, the required depth, D, becomes

$$D = \frac{S\ 0.164}{kL_o} = \frac{3.2\ S}{L} \qquad [81]$$

Also the design loading, lb/acre, becomes

$$\text{lb/acre} = 0.976S \qquad (82)$$

(A lower loading of $\frac{1}{2}$ lb/BOD_5/acre-day, has been suggested by Hopkins (477a) for whey stabilization lagoons.)

The data of Fritz (374a) in the text of Fair et al. (350) indicate December average radiation levels of about 100 langleys in the Great Lake States and about 200 in the south and southwest. From this the design loads would be about 50 and 100 lb/acre for the Great Lake States and 100 and 200 for the Southern and Southwestern States according to the criteria above. These design estimates are substantially higher than those being used in practice as reported by Svore (1097a), Table 92.

Table 92 - Some Lagoon Design Practices

Area	Design Loading lb BOD_5/ave.	Reference
Missouri Basin	20	1097a
Upper Mississippi Basin	20	1097a
Great Lake States	20	1097a
Areas of Winter Icing		
No odor	10-15	838a, 838
Odor, 1-2 weeks	20	1097a
Odor, 3-4 weeks	25-30	1097a
Odor to 3 months	56-60	1097a
South, Southwest	to 50	1097a

Further, Porges (838) has commented that dairy wastes, then operating with odor problems and about 20 lb/acre, appeared to be more difficult to treat than municipal waste.

Thus the choice of a design conversion "efficiency" becomes the arbitrary critical factor in this design approach.

The pond depths suggested by equation (81) for dairy wastes, where L is often 1000 to 2500 ppm, are often less than a tenth of those apparently used in practice. The result is longer residence times, T, than predicted by kinetic equation (79).

No specific information is available regarding solids accumulation in aerobic lagoons for milk products. However, Sawyer (923b) has suggested that aerobic lagoons generally produce about 0.5 pound suspended solids/pound 5-day BOD. This amount is lower than found for skim milk at low temperatures or whey and some would likely be lost in pinpoint floc, as in activated sludge systems, at low loadings. A portion of the remainder would digest aerobically or anaerobically with perhaps as much as 30% remaining undegraded.

The Influence of Temperature on System Performance: A wide range of θ values for treatment rate constants k have been reported.

$$\frac{k_2}{k_1} = \theta^{T_2 - T_1} \qquad [83]$$

Some of these are shown in Tables 67 and 93. No data were available for milk waste treatment systems.

Table 93 - Values of θ for Some Lagoons

Process	θ	Reference
Activated lagoons		
Batch	1.06-1.09	314
Continuous	1.035	Sawyer in 314
Paper, continuous	1.07-1.09	312a
	1.065	654c
Aerobic		
	1.07-1.08	654d
	1.085	657ab
	1.047	877a
Anaerobic		
Methane, < 15°C	1.0	799a
16-22	1.14	779a

We agree with Eckenfelder (314) that experimental confirmation of the temperature coefficient θ is desirable.

Much of the heat loss is by evaporation and convection from the free surface of the lagoon.

Mancini and Barnhart (654c) have expressed a simplified heat balance in the form

$$T_i - T_w = (T_w - T_a)\, fA/Q = (T_w - T_a)\, f\, \tau/D \qquad [84]$$

where

T_i = influent waste temperature
T_w = lagoon water temperature
T_a = air temperature
A = lagoon surface area, ft^2
Q = influent flow (mgd)
f = proportionality factor
τ = nominal detention time $V/Q = AD/Q$
D = depth

Logarithmic probability distributions for f for aerated lagoon temperatures in the Eastern and the Midwestern United States were reported.

Fifty and 90 percent probability values for f were reported to be 3.5 and 9 for the Eastern states, 38 and 62 x 10^8 for the Midwestern states, respectively.

Nutrient Requirements: Nutrient requirements for lagoon waste treatment of dairy wastes have not been established. N/BOD and P/BOD values of 4 to 5 and 1, respectively, have been suggested for aerated or aerobic lagoons (312a, 402a). Experiences reported earlier for activated sludge treatment of milk waste suggests that NH_4 nitrogen will be more successful than NO_3 nitrogen. Industrial success with nitrogen supplementation for lagoons or activated sludge has been variable. The difficulty in treating dairy wastes in stabilization ponds was said to be reflected by the low loadings reported. All but the pond operating at 51 lb/acre/day apparently gave satisfactory treatment. Porges (838) commented, "Apparently dairy waste can be treated without nuisance only at relatively low pond loadings." No information on the performance of the one aerobic-anaerobic, the two anaerobic ponds, and the four undesignated ponds were given in this report.

Later Porges (838a) was quoted (1097a) as recommending a design rate of 10 pounds of BOD per acre-day with a standard 4-to-5 depth to eliminate usual odor problems. Svore (1097a) maintains that a 20-pound BOD per acre loading appears to keep odors at a reasonable minimum, i.e., persisting not more than a week or two after the ice break-up. Loadings of 25 to 35 pounds BOD per acre-day were said to cause odors persisting for as long as three to four weeks while higher loadings of 50-60 pounds may cause odors that persist as long as three months.

Stouse, D. C., (1062) reported on the design data for several ponds processing dairy or dairy and municipal wastes. This survey was conducted while the author was a member of the Iowa State Department of Health and was made between January, 1961 and March, 1962. The treatment efficiency for these installations were not given explicitly. Scatter diagrams for effluent BOD, effluent ammonia, ppm, and effluent coliform counts versus organic surface loading are given for both summer and winter operations. No specific design loading rate were suggested.

Experiences with Dairy and Whey Wastes

Carl (210) reported on the application of stabilization ponds to the treatment of combined dairy and municipal wastes in South Dakota. Design data were given for seven facilities treating combined dairy and domestic waste with a BOD loading of 11%. In all but one instance the design loadings for these installations were on the order of 20 lb BOD/acre/day. Loadings of this magnitude were said to have resulted in no serious odor problems except in those instances where whey and buttermilk have been discharged into the system. Diligent operation of dairy plant control by municipal ordinance was said to be required to prevent such accidental discharges. Treatment efficiencies are not reported. Liquid depths of 3 to 5 feet were suggested. High sulfate content of waters was said to contribute to more serious odor problems. If more than one cell in a series are required, the loading on the primary cell was suggested to be 15-20 lb BOD/acre/day.

Porges (830) summarized the limited data he had available on the 827 industrial waste stabilization ponds in the United States at that time. Twenty-four of the stabilization ponds reported were treating dairy waste primarily. Two of these were in the Middle Atlantic region, 6 in the East North Central region, 13 in the West North Central region, 1 in the Mountain States and 2 in the Pacific States. For the 17 aerobic ponds, 9 consisted of one cell, 7 of series, 1 of parallel ponds. The areas varied from 3 to 11 feet with an average of 5.0; detention time varied from 35 to 728 days with a median of 98. The loading varied from 5.3 to 85 with a median of 22. Of the 15 reporting ponds, 74% reported yes, the system was effective; 20% had no knowledge. The BOD of the only sustem discharging to a water course was 95%. Of the nine reporting nuisances, five indicated that the nuisance was predominantly odor.

Svore (1097a) cites work in North Dakota in 1948 as the basis for the 20 lb of 5-day BOD per acre allowable loading in the Missouri basin, Upper Mississippi basin, and the Great Lake States. This is light for loading because some areas from the Northern States was chosen primarily on the basis of odor control. This problem of odor control was said to be the single most important item for consideration for the design engineer in the Northern Middle Western States today.

In the spring of 1952, the State Health Department of South Dakota (97) investigated odor problems developing at 97 sewage stabilization ponds in that state. The study indicated excessive discharge of milk processing wastes such as whey or buttermilk as the cause for the majority of the odors. The sulfate content in the water supplies was said to be a contributing factor.

Svoboda, M., et al. (1096) studied the treatment of the waste from a dairy plant in Czechoslovakia by three aerobic lagoons. The microbial flora in the system was discussed.

Another study of odor nuisances in combined stabilization ponds in Canada also attributed many instances of odor problems to the concentration of dairy waste (1193).

In 1963, Parabrahram and co-workers (785) reported on laboratory and pilot scale studies of dairy waste treatment in lagoons. In the laboratory Chlorella and Chlamydomonas species reduced the BOD of dairy waste from 66 to 93 percent. In pilot scale studies in India BOD reductions of 52 to 74 percent were obtained for loadings of 490-520 lb/acre-day for a 4-foot depth and a 12-day detention time. In studies then in progress with higher loadings acidic wastes were followed by algal disappearances, septic appearance, insect problems and slow recovery. Overloading was reported to have produced a thick algae floating mass, and again, pond failure.

Maloney and others (654) studied the effect of whey wastes on the performance of stabilization ponds treating municipal and dairy wastes. The system included primary clarification, separate sludge digestion with sludge drying beds, and discharge of the supernatant to three ponds, operated in parallel. The effluent to the lagoons was approximately 210 ppm following clarification. BOD was applied at a loading of between 50-70 pounds per acre day. At this location the 40-year minimum temperature is 28.7°, maximum 79.6° in January, and during July, the warmest month, the minimum is 66.1° and the maximum 113.7°. Cloud cover was infrequent. Poor performance was indicated by H_2S gas, black sludge and later by the low concentrations of dissolved oxygen and desirable algae, as well as the presence of dissolved sulfides. Addition of nitrates had no detectable effect. This treatment had been reported to be effective in preventing sulfide odor problems in cannery waste lagoons and in preventing anaerobic conditions. Zack (1286) added nitrates to improve the performance of dairy waste lagoons. However, Porges et al. (837) were unable to improve aerobic BOD removal rates by the addition of $NaNO_3$ to laboratory scale fermentations of skim milk.

Diversion of BOD from one lagoon to the others was investigated. The under-loaded lagoon showed an increase in green algae species and a decrease in sulfides, while the lagoons with the increased BOD and hydraulic loads showed the opposite effect. When the loading of a pond was stopped a pond improved gradually and after two weeks became aerobic throughout its depth. Also the algal population which became established once more was predominantly of the desired green species. However, when normal loading was reestablished the pond promptly returned to the unsatisfactory condition.

A search for toxic materials eliminated most effluents but exposed the continuing discharge of whey to the sewer. In one instance disturbance was attributed to the presence of a large amount of whole milk which was discharged to the sewer because penicillium content prohibited the growth of the toxic material. During these upsets the maximum load to whey ratio was estimated to be 0.35% of the hydraulic load.

Elimination of the dairy wastes from the sanitary sewage dropped the BOD of the clarified sewage from 210 to 100 ppm in November and to 30 ppm in June.

Three pilot size ponds, each 13 x 40 feet, were constructed with a 3-foot normal operation depth. The detention period was 10 hours. Clarified sewage was fed at a rate which gave a nominal five-day residence time; however, evaporation, absorption and percolation were sufficient to give no effluent.

When whey was added at the rate of five gallons per day the system performed poorly. Apparently the whey caused an increase in algal numbers of a yellow-green species. Whey whey feeding was discontinued the pond recovered slowly. The addition of calcium nitrite appeared to aid the recovery of the pond. Later the whey was added once more but at a lower rate of two gallons per day. Even at that loading the system appeared to be performing poorly. When the whey load was increased to 2.5 gallons per day the performance of the system did not seem to change. But, when the loading was subsequently increased to three gallons per day dissolved sulfides were found at the bottom of the pond. Even after whey was discontinued, as much as one week after whey loading, the sulfides were detected on the bottom of the pond. In another pond, whey was added without the addition of nitrate; this pond performed satisfactorily at one gallon per day. However, like the other pond, it performed marginally at the rates of two gallons per day and poorly at the rate of 2.5 gallons per day.

Residual effects of whey were reported two months after dairy wastes had been eliminated from the sewage system for the larger ponds. A somewhat larger tolerance was observed with the addition of nitrates.

The authors concluded that the ponds could tolerate a hydraulic loading of two gallons per day, i.e., 0.32% whey. We estimate that the corresponding BOD load contributed by the whey to be equal to double the BOD contributed by the clarified dairy waste free municipal waste.

Maloney et al. (654) suggested that the poor performance was associated with the accumulation of proteins in the bottom of the pond. This accumulation of proteins was said to be due to the slower oxidation of proteins as contrasted to lactose. A breakdown product of these precipitated proteins was thought to be sulfates. These sulfates were believed to enhance the growth of sulfate reducing bacteria. If the activity of the sulfur bacteria was not also accelerated, H_2S might form and then react with the iron in the waste. The sewage contained sulfide and about 2,000 ppm dissolved solids which was primarily sodium chloride. The city water itself had 280 ppm sulfate.

Oswald (799a) later commented on this installation at El Centro, California. He commented that milk whey wastes produced a sour sludge which did not digest under the variable pond environment. Evidence for this was said to be the lack of methane fermentation, low pH, and excessive algae production, the latter due to the intensive sunlight. The design depth had been 5.4 feet, equivalent to 3.5 or 4 feet in the "average climate," but the depth during the studies by Maloney et al. (654) was only about three feet due to a lack of water. Subsequent operation at 7-foot depths was said to present methane fermentation with greatly reduced nuisance conditions.

Recently El-Baroudi and Moawad (323) have reported on the rate of BOD reduction by oxidation ponds. Two pilot scale stabilization ponds with surface areas of 13.2 square meters and volumes of 6.8 cubic meters per pond were used. Water depth was maintained at 0.9 meter. During the first run only the first pond was used. The average temperature ranged between 24-33°C and the maximum light intensity was approximately 1450 footcandles. The average loading rate was 70 lb BOD/acre day. The second run, which was in the winter, had an average temperature ranging from 12-21°C and an average maximum light intensity of about 885 footcnadles. The loadings for the first pond were 82.6 lb BOD/acre day and for the second was 165 lb BOD/acre day. The third run in the late winter had average temperatures ranging from 15-25°C, and an average maximum light intensity of about 1270 footcandles. The loadings on the ponds were about 93 and 46 pounds of BOD/acre day, respectively. These ponds were fed every other day in a manner to simulate detention period of ten days and a continuous flow system.

The BOD contents of the pond before and after feeding and of the added feed were made daily for the 20 to 24 day run times. Mass balances were made to follow the amount of BOD stabilized between feedings, the amount of BOD added in milk, the point and cumulative BOD removal efficiencies.

Each of the ponds, including the one before feeding, in the first of three experiments showed cycle variation in the BOD levels. In some instances the BOD of the pond increased rather than decreased between feedings. Some investigators might prefer to work COD rather than BOD because its meaning is not complicated by BOD removal kinetics. In three instances during Runs 2 and 3, the BOD of the pond water after feeding was less than before feeding. The authors attribute this to interference of algal components with the BOD test measurement.

The algae flora varied from run to run. During the first run in October the predominant flora were blue-greens with *Anabaenopsis* trichomes and *Chroococcus* cells. A few *Trochiscia* and extremely few *Chlorella*, *Scenedesmus* and *Chlorogonium* were found. The corresponding maximum daily temperature was about 33°C and the maximum light intensity was about 1460 footcandles. In December the earlier flora was gradually replaced by the predominance of green algae, such as in *Chlorogonium* and a corresponding reduction of *Chroococcus* and *Anabaenopsis*. Here the maximum temperature was about 21°C and the maximum light intensity was about 845 footcandles.

In February *Chlorogonium* species flourished and *Chlorella* and *Scenedesmus* also appeared in considerable numbers. During this period the maximum pond temperature was about 25°C and the maximum flux was about 1280 footcandles. The numbers of *Chroococcus* and *Anabaenopsis* cells had nearly disappeared.

El-Shakawi and Moawad (343) made an extensive study of the algae flora in pilot plant scale oxidation ponds. In reviewing the literature they noted the frequent reports of odor problems. They conclude from the study of Porges (1963) that only at a low loading rate of about 15 lb/BOD/acre-day and extended detention time of at least 35 days was generally satisfactory stabilization achieved. In their study, a simulated dairy waste was applied at the rate of 220 lb/acre-day. The lagoons were fed only during daylight hours to simulate normal processing in that region. Detention periods were approximately 10 days and BOD reduction of 80-90% were reported during the experimental period. The sunlight intensity reached a maximum of slightly less than 50,000 luxes during September and about 90,000 luxes during August. Maximum pond temperatures were about 18°C in December and 37°C in August.

The development of acidity by milk bacteria such *Streptococcus lactis* and *Lactobacillus* species was suggested as a cause for poor algae development and was the explanation of the partial failure of dairy waste treatment oxidation ponds in the U. S., Canada and India (785, 838, 779b, 654, 1193).

Pre-treatment with alkali or incorporation of the high pH cleaning wastes to raise the pH to the alkaline range to permit growth of desirable algae was suggested.

Pond water was reported to support algal flora different from that which would normally develop in domestic substrates. The flora for milk wastes were classified in three groups, the dominant-subdominate *Pandorina*, *Navicula* and *Oocystis*; the occasional subdominants, including *Carteria*, *Cosmarium* and *Euglena* and a transitional flora of *Chroococus*, *Chlorogonium*, *Scenedesmus* and *Selenastrum*.

There is no discussion why the flora for an earlier study (323) at the same location were largely of the "transitional" group. The experimental differences were that the earlier study used pasteurized skim milk, rather than plant waste; used a depth of 0.9 meter near the one meter of the deepest lagoon in this study and the loadings were only 47 to 165 as compared to 220 lb/acre day in this study.

Further, these dominant species are different than those found by Raschke (864). Fourteen of the 28 species found had not been previously reported in other waste ponds. Further, *Anabaenopsis elenkinii*, *Ankistrodesmus falcalus* var. acicularis, and *Kirchneriella lumaris* var. *irregularis* were dominant at some time during the sampling period with *Euglenales* esp. *Euglena acovs* being most prevalent. The pond depth was also reported to have an influence on the flora of the pond. A depth of 75 cm was found most convenient according to the appearance of the pond. At this step the color of the pond was a deep green most the the time due to the optimum growth of *Pondorina*. At depths of 50 cm algae tended to settle out and the water became pinkish because of the presence of a considerable amount of protozoa and rotifers. At the 100 cm depth there was insufficient conversion to algae cells and sludge accumulation was noticed.

Since El-Baroudi and Moawad (323) have attributed a nearly 300 percentage change in K_1, the minimum apparent first order rate constant of a lagoon, to a change in flora, progressive flora changes with the season or following a process disturbance have been noted in all three studies (323, 343, 864) and further, the flora appear to differ from system to system. Further multidisciplinary studies are needed to form the basis for improved design and management of aerobic lagoon systems.

Performance Data

Available performance data for dairy waste lagoon systems are summarized in Tables 94 and 95.

Operational Problems

The primary operational problems for lagoons appear to be 1) odor control, 2) algae control and 3) temperature-performance control, with less serious problems regarding weed, erosion, and insect control.

Industrial experiences indicate that some measure of odor control can be attained by low loading for aerobic systems and by depth control for anaerobic systems. In aerated systems the degree of aeration may be increased as desired.

Algae growth and species control does not yet appear on a scientific basis. Depth control and skimming of algae mats are possibilities.

Operation of parallel ponds followed by one or more additional ponds permits loading and residence time control. Lagoons in series permit the higher efficiencies of staged operations for BOD and algae control. The option of longer residence times by putting longer parallel ponds in

Table 94 - Performance Data for Lagoon Treatment of Dairy Wastes

Product or Process	MGPD	Size, acre-ft	Time Retained, day	Loading lb/acre	BOD Red. %	BOD (ppm)		Sus. Solids (ppm)		pH	Remarks	Ref. No.
						Inf.	Effl.	Inf.	Effl.			
Dairy	--	--	--	--		3060	125	144	--	7.0	TS 1029 ppm	23
			--	--			75	154	--	7.55	T.T. 476 ppm	
Cheese Casein	0.056	5.6		106 T.	91	1700	153	--	--	--	Czech Loss 71% June, 56% Oct.	103,
					--	153	--	--	--	--	99.3% redn Total, 700 ft^3	(1088b)
					--	--	14	--	--	--	lagoon. Tellc Dairy	
Dairy	0.36	--	--	--	89.5	225	25	--	--	--	Aerated	104.5
Municipal												
54 % Dairy	--	16	--	11	Excel	--	--	--	--	--	Castlewood, S.D. 3' to 5' Fac.	210
57.0%	--	8.3	--	25	Excel	--	--	--	--	--	Freeman, S.D. 3' to 5'	
55.0%	--	12.3	--	17	Excel	--	--	--	--	--	Humbolt, S.D. 3' to 5'	
37.2%	--	15.5	--	22	Excel	--	--	--	--	--	Parkston, S.D. 3' to 5'	
18.2%	--	30.2	--	18	Excel	--	--	--	--	--	Redfield, S.D. 3' to 5'	
17.9%	--	13.1	--	20	Excel	--	--	--	--	--	Scotland, S.D. 3' to 5'	
92.0%	--	21.0	--	19	Excel	--	--	--	--	--	Volga, S.D. 3' to 5'	
Dairy	--	--	7	--	60 Av	--	--	--	--	--	Pilot. .0145 #/ft^3 day Anaerobic	221
			7	180	76-	--	--	--	--	--	Aerobic, Chlorella,	221
				-395	86						Scenedesolus sp.	
			13		70 winter							

Table 94 - Continued

Product or Process	Size, acre-ft	Time Retained, day	Loading lb/acre	BOD Red. %	BOD (ppm) Inf.	BOD (ppm) Effl.	Sus. Solids Inf. (ppm) Alk.,	Sus. Solids Effl. (ppm) D.O.	pH	Remarks Alexandria UAR	Tmin	Tmax	Ref. No.
Dairy	2.95'	10	31.7	-14-71	--	--	--	--	--	1450 ft.C	24	- 33°C	323
		10	--	--	--	--	--	--	--	"	24	- 33°C	
		10	37.5	-65-60	--	--	--	--	--	855	12	- 21	
		10	75.0	-83-60	--	--	--	--	--	"	12	- 21	
		10	42.3	10-60	--	--	--	--	--	1270	15	- 25	
		10	21.0	-40-60	--	--	--	--	--	"	15	- 25	
Dairy Plant	1.63'	10	220	--	750	--	180	10	7.0-8.2	8360*	24	30	343
				77.0	750	160	185	20	6.0-6.5	8000	25	32	
				88.5	750	82	190	13	6.0-7.0	"	24	30	
				89.5	750	75	190	19	7.0-7.3	"	23	28	
				93.0	750	50	190	10	7.7-8.4	"	21	26	
				96.5	750	25	200	7	8.0-8.5	7250	22	27	
				95.0	750	35	210	11	8.0-8.5	"	20	25	
				90.0	750	70	220	11	8.0-8.5	"	23	27	
				89.5	750	75	220	10	7.8-8.0	"	23	28	
		10	220	86.0	750	100	180	12	6.0-7.0	8000	24	32	
				90.0	750	73	180	10.6	6.0-6.5	"	23	30	
				92.0	750	56	200	11.0	7.0-7.2	"	22	28	
				91.0	750	64	200	7.0	7.7-8.4	"	20	26	
				86.0	750	100	200	12.0	8.0-8.4	7250	21	27	
				90.0	750	75	200	10.0	8.0-8.5	"	19	25	
				90.0	750	70	210	20.0	8.0-8.5	"	22	27	
				90.0	750	70	220	12.0	8.0-8.5	"	22	28	
				84.5	750	110	230	11.0	7.0-7.7	6300	21	27	
				83.0	750	120	240	12.0	7.6-7.9	"	19	24	
				84.5	750	110	220	8.0	7.0-7.3	"	12	19	
				84.5	750	100	220	8.0	7.0-7.6	5400	13	19	
				82.0	750	120	220	7.0	7.2-7.3	"	11	17	
	3.28'	10	220	86.0	750	100	200	6.0	7.0-7.7	6300	22	27	
				80.0	750	140	200	11.0	7.4-7.7	"	18	24	
				81.5	750	130	210	5.0	7.0-7.2	"	13	19	
				80.0	750	140	220	4.0	7.0-7.6	5400	14	19	
				81.5	750	130	210	3.0	7.2-7.3	"	12	17	

Table 94 - Continued

Product or Process	MGPD	Size, acre-ft	Time Retained, day	Loading, lb/acre	BOD Red. %	BOD (ppm) Inf.	BOD (ppm) Effl.	Sus. Solids (ppm) Inf.	Sus. Solids (ppm) Effl.	pH	Remarks	Ref. No.
Dairy	--	--	30 -45	--	--	6000 -10000	450 800	-- --	-- --	-- --	Belgium Approx. 50% Loss. Eff. Treat. by act.sludge	363 (102)
Dairy	--	3.9'	12	82	66 -93	--	--	--	--	--	India Chlorella, Chlamydomonas sp.	363 (785)
Municipal Dairy	--	--	--	68	75.9	149	36	--	10	--	D.O. eff 6 ppm. Def prior treat by T.F.	413
Cheddar, Milk, I.C.	0.012 other 0.011 whey	--	--	--	None	4500	--	--	--	--		500
Multi	0.172	6x0.5ea	--	325 -3400	--	90 -900	0 200	--	--	--	Aerated Ice cream, sour cream, buttermilk powder, 175-1700 ppD; spray recycle to cells above.	500
Dairy	0.0053	1st .12 2nd .3		--		85 --	-- 25	--	--	--	Raised carp. Diluted waste with creek.	522
Cheese		1st 0.06x8' 2nd 3.9x5'	18	--	80%	200 -29000	--		188 -1288	-- 6.2-7.1	Series. 1st aerated - 10 Hp. Periodic discharge to stream (6 mos)	542
Milk Parlor	0.00076	--	--	--	45.6	1030	470	--	--	--	Anaerobic, 9 lb/1000 ft^3, 85°F	634
					67	470	155	--	--	--	Anaerobic, .6 lb/100 ft^3 lower eff. winter	634
Cheese w/o whey Receiving Creamery General w/o whey	--	--	--	64 48 64 56	--	--	--	--	--	--	Missouri State Stds.	711a
84% Cheese 12.6% Domestic 3.4% Creamery	0.690	3 lb.13Total 10'		261	93 -99	--	10 -37	--	10	--	Aerated. 1700 cfm#1; 458 #2; 258 #3; recirculation #2 to #1. 29%; 13-33% loss winter	751b
Dairy	--	7.5; 1'	8	--	53	75	35	--	--	--	Set in Imhoff, TF, set, Lagoon 85% redn overall	768
Cheese -Municipal	--	3'-5'	120	20	74 -86	--	--	--	--	--	Recommendations, Dakotas	777
Dairy	--	--	12	490-520	52 -74						India, Pilot	785

Table 94 - Continued

Product or Process	MGPD	Size, acre-ft	Time Retained, day	Loading, lb/acre	BOD Red. %	BOD (ppm) Inf.	BOD (ppm) Effl.	Sus. Solids (ppm) Inf.	Sus. Solids (ppm) Effl.	pH In	pH Out, Max	Remarks	Ref. No.
Skim milk	--	--	4.9	--	89.0	--	--	--	--	6.85	8.1	1,000 ft. candles	815
			10.1	--	86.4	--	--	--	--	6.85	9.6	"	
			19.2	--	82.8	--	--	--	--	6.85	10.2	"	
			28.1	--	74.0	--	--	--	--	6.85	9.9	"	
			5.1	--	64.7	--	--	--	--	8.8	11.1	"	
			9.6	--	68.2	--	--	--	--	8.8	11.1	"	
			19.2	--	77.8	--	--	--	--	8.8	10.9	"	
			30.3	--	82.6	--	--	--	--	8.8	10.8	"	
			4.7	--	95.6	--	--	--	--	7.5	11.2	"	
			9.7	--	87.7	--	--	--	--	7.5	11.2	"	
			12.2	--	83.6	--	--	--	--	7.5	11.1	"	
			32.4	--	83.1	--	--	--	--	7.5	10.3	"	
			4.8	--	95.3	--	--	--	--	7.5	11.0	"	
			9.1	--	90.9	--	--	--	--	7.5	11.0	"	
			18.5	--	82.0	--	--	--	--	7.5	10.6	"	
			27.7	--	80.3	--	--	--	--	7.5	9.9	"	
			3.3	--	74.8	--	--	--	--	8.7	11.5	1,600 ft. candles	815
			3.1	--	85.2	--	--	--	--	7.5	11.0	"	
			3.2	--	89.4	--	--	--	--	7.0	10.8	"	
			3.3	--	94.3	--	--	--	--	6.5	10.5		
			20.6	--	76.3	--	--	--	--	8.5	11.0	"	
			19.2	--	78.0	--	--	--	--	7.5	10.9	"	
			21.3	--	81.2	--	--	--	--	7.0	10.8	"	
			19.7	--	85.1	--	--	--	--	6.5	10.6	"	

Table 94 - Continued

Product or Process	MGPD	Size, acre-ft	Time Retained day	Loading lb/acre	BOD Red. %	BOD (ppm)		Sus. Solids (ppm)		pH	Remarks	Ref. No.
						Inf.	Effl	Inf.	Effl.			
Dairy -Municipal	--	0.07	--	--	--	--	--	--	--	--	Y (Y = aerated, P = Pretreatment)	838
		10.5	410	22.8	OK	--	--	--	--	--	Y-Y S = some domestic)* est, ** design)	
		3	370	15	95	--	--	--	--	--	Y-Y-Y odor	
		--	--	--	OK	--	--	--	--	--	Y odor	
		1.5	--	--	OK	--	--	--	--	--	P-Y odor	
		8.3	90	51	OK	--	--	--	--	--	P-Y(S) odor	
		13.1	--	20**	OK	--	--	--	--	--	Y-Y(S) odor	
		15.5	--	22**	OK	--	--	--	--	--	Y(S)	
		21	--	24**	OK	--	--	--	--	--	Y Y Y(S)	
		30.2	--	18**	OK	--	--	--	--	--	Y	
		15.0	--	12**	OK	--	--	--	--	--	Y-Y(S)	
		8	49.3	44*	OK	--	--	--	--	--	PY	
		7	35	--	--	--	--	--	--	--	PY	
Dairy	--	14.8x 3.2'	--	--	--	--	--	--	--	--	2640 gal/day processed for fish ponds. 5 ton/lime/acre year	855
Dairy w/o whey	--	8.6 x3.2'	--	--	--	--	--	--	--	--	2640 gal/day processed for fish ponds. 5 ton/lime/acre year	
Creamery	--	--	--	40	--	--	--	--	--	--	Iowa	1062
248 Creamery	--	--	--	45.4	--	--	--	--	--	--	"	
Dom. Cream, Meat	--	--	--	20.6	--	--	--	--	--	--	"	
235 Creamery	--	--	--	20	--	--	--	--	--	--	"	
105 Creamery	--	--	--	15.6	--	--	--	--	--	--	"	
Dairy	--	1.85	38-63	--	--	1200-2500	142-1240	--	--	5.2-6.3	5-18°C	1096
	--	2.0	42-66	--	--	--	101-281	--	--	6.3-7.5	4.8-30°C	
	--	1.73	34-56	--	--	--	33-171	--	--	6.5-7.5	0-18.3,	

Table 95 - Aerated Lagoon Performance as Reported in the Industrial Survey

Plant	Secondary Treatment Method	Raw BOD		Treated BOD		% Reduction	
		Range	Ave.	Range	Ave.	Minimum	Average
54	Aerated-2 lagoon system	-- Went septic at 1700 ppm with whey	1000	--	20	--	98.0
50	Aerated-2 lagoon system	20-70	40	10-20	12	0	70

series or by increasing depth to avoid discharge provides a means to compensate for upsets or reduced performance in the winter.

Solids buildup is still an undefined problem for dairy wastes. Larger buildup is expected for systems with cheese fines, fruits or nuts or for whey.

The slow response of aerated or aerobic lagoons to process disturbances does not appear to be a real advantage because process upsets are difficult to detect; relatively little is known upon which to base a response and system recovery is so slow. When confronted with such circumstances the process engineer responds by underloading to reduce the likelihood of an upset. The reduction in loads from the time of the Porges survey (838) to the comments of Svore (1097a) suggests that the sanitary engineer has done the same.

Since lagoon systems often have been the economic waste treatment approach for systems with the population equivalent of less than 2.5 MGPD, dairy equivalent of $< .25$ MGPD, more research is necessary to permit operation at significantly higher loading levels.

IRRIGATION

In the last fifteen years wastes from small dairy plants in rural areas have often been spread on fields using the same application as those techniques used in irrigation. The relatively low cost and apparent ease in management are particularly attractive for these operations.

Case studies, such as those by Schraufnagel (950-2), McKee (680-3), Lawton and co-workers (191, 612, 613), Arbuckle and Blanton (124), Scott (991), and Magnusson and co-workers (647, 1201), have documented many successful and some grossly unsuccessful operations. Run-off, ponding, odors or marked loss in infiltration, and loss of cover crop were signs of failure. Success is more difficult to measure since there is not yet an integrated biological oriented design approach; measurement of ground, surface and soil waters is difficult, and often the economic base of operation has been small.

The sand filter appears to be the closest sanitary engineering analog for the land disposal of dairy processing waste; however, biological, as well as physical treatment, are required.

McDowall and Thomas (677), among others (124, 191, 612-3), have applied the principles of irrigation to the application of dairy waste water. They gave some attention to the problems of irrigating with potentially saline wastes, but because of the nature of New Zealand soils did not need to be concerned with drainage for control of leaching or high water tables. Many years ago Eldridge (325) examined the feasibility of the sand filter, as well as larger aggregate trickling filter approaches to dairy waste treatment. Again metabolism of dairy wastes often yielded lush biological films which often reduced the capacity of the sand filter. More recently, Castrostopoulos (251) has examined the kinetics course of BOD reduction in sand filters for periodic or continuous loading of skim milk waste. However, kinetic approaches appear to have not yet been applied or evaluated in milk treatment practice. These and related studied concerning irrigation of dairy waste waters will be considered below:

The Hydraulic Approach: McDowall and Thomas (677) prepared a manual on disposal of dairy wastes by spray irrigation on pasture land for the Dairy Waste Committee of the Pollution Advisory Council, Wellington, New Zealand, in 1971. The publication included material on waste conservation and how to make infiltration tests setting up the irrigation system. The material provided is generally sufficient for application of wastes by spray irrigation systems.

The maximum rate which may be applied is that which will satisfy the needs of the cover crop, other evaporation, and the infiltration capacity without exceeding field capacity. Run-off without surface detention times sufficient to give "aerobic" treatment are undesirable.

The authors cited Table 96 showing the U. S. Soil Conservation Service maximum application rates for water for various soil types and slope. After making allowances for rainfall, they then suggest recommended applications of dilute waste for soil types for both fine weather and rainy weather as shown in Table 97. Table 97 was said to represent an estimation of suitable rates for average conditions based on the assumption that irrigation will be continued for eight hours daily. The assumptions were that (1) the absorptive capacities after gravity draining vary from five inches per foot of depth for coarse sandy soil, to three inches of depth for heavy clay, and (2), on the average the absorptive capacity available for the disposal of water is from 1/2 for coarse sandy soil, to 1/10 for heavy clay, of the total absorptive capacity immediately after draining.

The USDA Soil Conservation Service, in cooperation with the state universities and the U.S. Weather Bureau, provide regional irrigation guides. These guides provide moisture extraction depth of the cover crops, maximum application rates for various soil management groups and rcommended maximum crop irrigation intervals. Similar guides are available for drainage, which are useful for water table control. These activities also provide soil maps and reports of monthly and annual precipitation probabilities.

Other useful source materials for U.S. applications are the American Society of Agronomy monographs on irrigation of agricultural lands (423a), drainage of agricultural lands (637a) and texts such as those by Israelsen and Hansen (508a) or Schwab and co-workers (984a).

Table 96 - Maximum Application Rates for Water as Recommended by United States Soil Conservation Service (1166a)

Soil Type	Application Rate (inches per hour*) for Slope of:							
	0-5%		5-8%		8-12%		12% and Over	
	With Cover	Bare	With Cover	Bare	With Cover	Bare	With Cover	Bare
Coarse sandy soils uniform to 6 ft. depth	2.0	2.0	2.0	1.5	1.5	1.0	1.0	0.5
Coarse sandy surface soils over more compact subsoils	1.75	1.5	1.25	1.0	1.0	0.75	0.75	0.4
Light sandy loams, uniform	1.75	1.0	1.25	0.8	1.0	0.6	0.75	0.4
Light sandy loams over more compact subsoils	1.25	0.75	1.0	0.5	0.75	0.4	0.5	0.3
Silt loams over more compact subsoils	0.6	0.3	0.5	0.25	0.4	0.15	0.3	0.1
Heavy-textured clays or clay loams	0.2	0.15	0.15	0.1	0.12	0.08	0.1	0.06

*1 in. per hour = 22,600 gallons per acre per hour (g.p.a.b.)
10,000 g.p.a.b. = 0.44 in. per hour

Table 97 - Recommended Applications of Dilute Waste per Irrigation
(1 in. = 22,600 gallons per acre)

Soil Type	For Use in Fine Weather	For Use in Rainy Weather*
Coarse sandy soil --	in.	in.
6 in. deep, poorly drained	1.25	0.25
12 in. deep, poorly drained	2.5	1.5
18 in. deep, poorly drained	3.75	2.75
Well drained	12.0	11.0
Light sandy loam --		
6 in. deep, poorly drained	0.9	
12 in. deep, poorly drained	1.8	0.8
18 in. deep, poorly drained	2.7	1.7
Well drained	8.0	7.0
Silt loam --		
6 in. deep, poorly drained	0.6	--
12 in. deep, poorly drained	1.2	0.2
18 in. deep, poorly drained	1.8	0.8
Well drained	3.5	2.5
Clay loam --		
6 in. deep, poorly drained	0.35	--
12 in. deep, poorly drained	0.7	--
18 in. deep, poorly drained	1.0	--
Well drained	2.0	1.0
Heavy clay --		
6 in. deep, poorly drained	0.15	--
12 in. deep, poorly drained	0.3	--
18 in. deep, poorly drained	0.45	--
Well drained	1.0	

*In unusually extended periods of heavy rain these figures may have to be reduced.

Resting between dosing was suggested (1) to avoid scorching of the pasture, (2) to provide time for recovery of growth and for utilization of the growth by livestock or by harvesting, (3) to allow the resting period to permit destruction of a biological film produced by the nutrients, and (4) to allow time for the dissipation of possible contamination by tuberculosis or other pathogenic organisms. A dosing cycle of 4 to 10 days was recommended for general dairy effluents but not for whey or casein washings. A resting period of two to four weeks was found to be sufficient in New Zealand to obtain sufficient forage production. A resting period of at least 10 days was suggested for avoidance of tuberculosis in line with the New Jersey State Board of Health recommendations.

Eckenfelder (311a) applied the following formula to predicting the quality of waste water which can be applied to an acre of land after equilibrium conditions have been attained.

$$Q = (328 \times 10^{-3})KS \qquad [85]$$

where

Q = steady rate for downward flow, gpm/acre

K = overall coefficient of permeability for the soil for the distance between ground surface and ground water table, ft/min.

S = degree of saturation, this could be 1.0 under steady state conditions.

He suggested that the site could be level; covered with vegetation; light soil texture; high sand and gravel content avoiding high clay content; spray tested and soil analysed prior to full scale irrigation; and cultivated to prevent compaction. Ground water levels at least ten feet below the surface were said to be necessary to allow the proper decomposition of waste as well as more rapid percolation.

Lawton et al. (612,613) have reported that hot wastes may damage a cover crop but often may be successfully irrigated by elevating the spray nozzle to permit evaporative cooling before contact. The temperature of the dairy food plant wastes are expected to vary widely but average 30°C. With an aerated holding tank with about three fourths day detention time ahead of irrigation, the temperature of the applied waste should be about 25-30°C.

Proper irrigation is suggested as a means to permit oxidation of organic materials and restoration of permeability. However, the large amounts of easily oxidizable material which occur in milk wastes are said to constitute no serious problem when the irrigation system is well managed.

Lawton et al. (612, 613) noted the problems of ponding which could occur on relatively level land with poor drainage. In a particular instance the soil was sandy loam overlying a very slowly permeable clay at a depth of two feet. Under these conditions the loading rates will be almost entirely dependent upon transpiration and evaporation, which would be about two-tenths of an inch per day during the growing season in the Wisconsin area. At another site permeability had nearly ceased following irrigation for several years with water of relatively high organic content. The soil, which was a clay loam, had increased in organic content from 1.8% for the unirrigated areas to 2.9% for the irrigated areas of the field. The clogging was attributed to filling of soil pores by bacteria, slime molds and other growths as a result of lack of ae ation.

Lawton et al. recommended no specific design criteria except caution to observe the health of a crop as a means of judging excessive application. A similar position has been taken by McKee (680). He also maintained that hydraulic load was much more significant than BOD load.

Deep rooted grasses such as Reed's canary grass are suggested to be most satisfactory. Ponding with odor development has been noticed in areas where sprinklers were not moved frequently. Every day movement is suggested unless the soils are sandy. Precaution is especially necessary when the soil has low permeability or there is a high water table.

Odors were also noticed when holding tanks were sized for once a day irrigation in the winter or the contents became septic in the summer when aeration was not provided.

A screening unit was said to be desirable. The screen size suggested was one-fourth inch. This size is probably much too large to collect fines from cheese manufacture or small nut and fruit pieces.

One firm uses whey sedimentation prior to reverse osmosis to avoid clogging of the small pores with larger size casein particles. This is probably a good idea to reduce clogging of soils as well.

The Saline-Alkali Water Approach: Excess salinity or alkalinity content of waters for irrigation may adversely influence crop response or soil permeability.

Sodium ion is a particular problem because an excess in relation to other cations, especially Ca and Mg, may lead to disintegration of clays in soil with subsequent ponding.

Wilcox (1248) has suggested that the sodium content of water for irrigation should not be more than 80% of the soluble mineral ions present, that is, sodium x 100/calcium + magnesium + sodium ++) and that the total concentration of cations in equivalence per million should not be greater than 25.

Subsequently, the U.S. Salinity Laboratory staff (874) have recommended that sodium-adsorption ratio, SAR, be used with the conductivity, C, μmho/cm to classify irrigation waters.

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\left(\frac{\mathrm{Ca}^{++} + \mathrm{Mg}^{++}}{2}\right)^{1/2}} \qquad [86]$$

where the bounds for low, medium, high, and very high salinity hazards are

$$\mathrm{SAR} = 18.87 - 4.44 \log C$$

$$\mathrm{SAR} = 31.31 - 6.66 \log C \qquad [87]$$

and

$$\mathrm{SAR} = 43.75 - 8.87 \log C.$$

The bounds for low, medium and high salinity hazards are 250, 750 and 2,250 μmho/cm.

McDowall and Thomas (677) have reported that the sodium/total cation ratio for milk with ash composition as shown in Table 98 is 17% and that for cheese whey according to Sharratt et al. (999a) is 23%. The compositions given by Schraufnagel (950) are 19 and 21%, respectively.

Based on the first Wilcox criteria (1248), irrigation of pastures with milk, whey or dilute solutions of them, appears unlikely to cause physical deterioration due to high sodium content. Such negative results have been reported by Stone (1061a), Chesters (225a) and Lawton et al. (613).

However, dairy waste waters also contain salt from manufacture of some cheeses, salt from sodium and chloride ions from cleaning agents and from water-softening compounds. These materials may raise the level close to the limit recommended by Wilcox (1248).

Lawton et al. (612, 613) made an analysis of the cation and the ion content of the wastes from five plants. Only the sodium concentration was of concern to the investigators. The high sodium content was not expected from the consideration of the sodium content in the milk itself. The major source for the phosphorous and potassium content was presumed to be from the cleaning compounds. The highly variable percentage of sodium in the plant wastes varied from 63% for Plant B to 44% for Plant E. This is below the threshold of 80 proposed by Wilcox, but is sufficiently high to be of concern.

Average values of 3.7, 5.9, 6.12, 10.2, and 11.4 for five different installations by Schraufnagel (951) are reported. Values for cheese factories are generally higher than for other milk plants.

Table 98 - Content of Mineral Matter and Nitrogen in Milk and Its Products and By-products (after 677)

Dairy Product	Unit of Measurement	Calcium as CaO	Sodium as Na_2O	Potassium as K_2O	Phosphorus as P_3O_5	Magnesium as MgO	Chlorine as Cl	Nitrogen as N
Whole milk	As percentage in the ash	20.1	8.3	26.8	26.8	2.80	14.1	--
Cream (40% fat)		12.1	5.0	16.1	16.1	1.70	8.5	--
Butter (1.6% salt)		--	0.9	--	--	--	1.0	--
Butter, unsalted		--	--	--	--	--	--	--
Skim milk		20.1	8.3	26.8	26.8	2.80	14.1	--
Buttermilk		20.0	8.3	26.8	26.8	2.80	14.1	--
Cheese whey		10.0	9.9	30.0	--	--	21.0	--
Rennet casein whey		9.2	9.0	30.0	--	--	21.0	--
Lactic casein whey		20.0	8.0	27.0	27.0	--	14.0	--
Whole milk	As percentage in the dairy product	0.151	0.062	0.201	0.201	0.02	0.105	0.55
Cream		0.09	0.037	0.121	0.121	0.012	0.063	0.33
Butter, salted		--	0.66	--	--	--	0.94	--
Butter, unsalted		--	--			--	--	--
Skim milk		0.159	0.065	0.211	0.211	0.02	0.110	0.57
Buttermilk		0.157	0.064	0.209	0.209	0.02	0.109	0.56
Cheese whey		0.05	0.066	0.202	0.101	0.01	0.114	0.136
Rennet casein whey		0.046	0.06	0.20	0.09	0.01	0.114	0.136
Lactic casein whey		0.15	0.6	0.20	0.2	0.02	0.1	0.130

McDowall and Thomas (677) report that the concentration of all cations in equivalents per million is 120 for milk and lactic casein whey and 89 for cheese and renin casein whey. These figures are considerably higher than the 25 equivalents per million criteria suggested by Wilcox (1248). Thus, some soil damage is likely. McDowall and Thomas report they were aware of no such reports of damage.

When the waste was sodium rich, Scropp (955) found damage to the growth of grasses. The damage to the soil can be controlled to some extent by the addition of lime.

Reduction of sodium concentrations in the effluent by diversion of caustic waters from boil-out and from water softening were suggested. The addition of lime, calcium chloride, gypsum, iron and sulfur or aluminum sulfate were suggested depending upon the individual soil problem. Dilution of wastes by including cooling waters was also suggested by Schraufnagel (1951). These fragmentary data suggest that initial cation analysis of dairy waste may vary sufficiently that perhaps analysis should be part of irrigation design and be monitored several times a year.

BOD Reduction: Costopoulos (251) studied the BOD removal by sand filtration of skim milk. The BOD histories showed a lag, a first stage and a second stage oxidation. The lag time was load-independent, and was not present when active first-stage oxidation was believed present.

For periodic loading the soil BOD was

$$L = L_0 e^{-knT} + \mathcal{L}\left[\frac{1 - e^{-k(n+1)T}}{1 - e^{-kT}}\right] \qquad [88]$$

and for continuous loading as

$$L = \frac{\mathcal{L}_0}{k} + \left(L_0 - \frac{\mathcal{L}_0}{k}\right)e^{-kt} \qquad [89]$$

where

L_0 = initial available BOD,
$\mathcal{L}$ = BOD applied per loading,
$\mathcal{L}_0$ = BOD applied per unit time,
T = time period for intermittent loading,
n = number of periods,
t = time for continuous loading, and
k = coefficient of rate of oxidation

For increasing times, the limiting kinetic relationships are

$$L = \frac{\mathcal{L}}{1 - e^{-kT}} \qquad [88a]$$

and

$$\lim L = \frac{\mathcal{L}_0}{k}, \text{ respectively.} \qquad [89a]$$

Costopoulos reported indications that the decrease rate of percolation is due to organic matter buildup, as indicated by available BOD, $\mathcal{L}$, which is a function of loading rate, irrigation interval, oxidation rate and time.

If irrigation is to be used as a means of dairy waste treatment, confirming experimentation with special attention on the factors influencing the change of k and soil microflora with repeated loadings, appears desirable.

Eldridge (325) reported on experimental studies of biological treatment of dairy wastes with sand filters, gravel filters, and other filtering.

Reductions from 90-94% in total solids for waste application were found for application rates at the rate of 50,000 gallons per acre per day with concentrations ranging from 22,000 to 57,000 ppm. The removal efficiency decreased progressively as amounts of 150,000, 200,000 or 250,000 gallons per acre per day were applied. In the latter instances, efficiencies from 71-85% with strengths of 1000-1600 were reported. The 200,000 gallons per acre per day application rate is said to be the maximum for efficient operations. Here the removal efficiencies ranged from 82-88%. Maximum BOD concentrations at 150 and 200,000 gallons per acre per day were said to be 15 and 1400 parts per million, respectively. Much trouble was experienced from clogging with high ponding encountered.

For "cannery waste treatment utilization disposal" Eldridge (328a) recommended sand filtration as one of the possibilities for secondary cannery waste treatment following chemical precipitation of screen waste. He reported 15% additional BOD removal for sand filtration after chemical precipitation and recommended a loading of two gallons per minute per square foot with provisions for backwashing. Clogging was again the principle problem.

The manual for sewage treatment design (14a) indicated that the acceptable rate of application for raw sewage under intermittent sand filters may vary from 30,000 to 75,000 pounds per acre per day, depending upon the strength of the sewage. The manual states that the dosing of the raw sewage is not usually practiced because of the nuisance of rapid clogging of the sand, odors and insect breeding.

Experiences with Whey: Sharrett et al. (988a) have reported an increase in soil aggregation resulting from dosing with whey. This aggregation increase was noted at application levels up to 40,000 gallons per acre per week. Above this level, physical deterioration of the soil was reported. Similar findings have been supported by plant growth trials. Tewes and von Gavel (1107) and Schropp (955) have both shown a greater stimulating effect on the growth of pastures on sandy soil than on loamy soil.

The addition of dairy waste to soil would be expected to influence the soil. Soils with low buffer capacity would be expected to have pH levels close to those for the effluent and, subsequently, all soils would be expected to have a slight decrease in acidity or a raise in pH.

When dairy wastes are added to soils, the microorganisms convert the lactose to lactic acid. This and other acids will subsequently be utilized with an accompanying decrease in acidity or increase in pH. These effects may be considerably larger for soil with low buffer capacity. This sequence of pH value changes have been observed by Hickerson and McMahon (455b) and Sharratt, Peterson and Calvert (988a).

Mitchell and Cassidy (712) reported on the utilization of casein waters for pasture irrigation.

An estimated one million gallons of whey and two and one-half million gallons of whey wash water were applied to the 14-acre test plot. The wastes were applied on each acre on a 7 to 21-day cycle at the rate of 2500-3000 Australian gallons per hour for three to eight hours. The soil was a Krasnozem developed on basalt.

The whey had a pH ranging from 4.2 to 4.6; an acidity in the range of 0.4 to 0.45%; the chloride approximately 3000 ppm; and suspended particles at a rate estimated to be content average 0.54% by weight, i.e., 3.5 to 10.4 pounds per 100 gallons.

Soil analysis showed a drop in pH from 5.4 to 5 and an increase in available phosphate. There was a buildup in chloride during the winter and spring months with a return to substantially lower and safer levels, due to leaching, in April. The high chloride contents were in the vicinity of 420 to 650 ppm in the top five inches of soil and had increased from about 80 to 500 ppm in the lower 5 to 10 inches in the period of July to October. Leaching decreased the values to 32 and 20 ppm for the upper five inches and in the next five inches, respectively. There was a general decrease in exchange calcium and magnesium. This effect was overcome by the application of dolomite in a quantity of two tons per acre. No visual symptoms of magnesium deficiency developed.

Two grasses common to Australia were utilized. The distribution of grasses was changed by the application of waste. Some scalding was evident when the proportion of whey was high, relative to wash water, and three inches per acre of effluent was applied in eight days. The soil was also observed to become soggy.

Scott (991) reported on the practical aspects of disposal of high organic content wastes on land. A number of application examples are given in this paper:

(1) Successful application of 3,000 pounds per day of whey on a 40-acre field without problems.

(2) The application of 50 tons per year without difficulty (999).

(3) Whey application on 61-acre test plots at rates ranging from 5800 to 70,000 pounds per day per acre on a nine-day application cycle. At the end of the 30-day test period, the cumulative loading ranged from 220,000 to 1,600,000 pounds per acre or from 0.76 to 5.1 inch per acre. Observations indicated ready assumption of whey in the sandy soil at all levels. The oat-alfalfa crop withstood the lightest application but was killed at the higher levels. Over-all harvest yield return was 32 bushels per acre including the areas of complete vegetation loss.

(4) An application of 1450 pounds per day on 10 acres for 45 successive days, amounting to 326 tons of whey (BOD 30-50,000 ppm) per acre, without odor problems runoff or fly breeding problems were reported.

(5) The maximum loading rate encountered was 300,000 pounds of whey for 80 consecutive days on six acres for a cumulative 2,000 pounds per acre. Whey accumulated at low areas, with production of maggots. New furrows were turned every 20-25 days when the infiltration rates were significantly reduced.

McDowell and Thomas (677) reported the application of whey to grassland under their conditions could be as much as 5,000 gallons of undiluted whey or its equivalent, or up to 10,000 gallons of lactic casein whey provided there is a resting period of about 14 days between dosings.

Schropp and Vogt (958) investigated the effect of whey waste on plant growth. In some experiments various proportions of whey and waste water were utilized as nutrient supplement for broad beans, maize, and spring barley on sand clay and loam soils. In additional experiments liquid manure was utilized in conjunction with fresh whey, whey after storage and mixtures of whey in dairy wastes containing various proportions of cheese dust.

The data shows that the addition of whey to clay soil did not significantly change the pH, but increased the pH one-half unit for loam and increased the pH from 6.5 to 8.3 for sand. Proportional pH changes were observed for water and whey mixtures.

The addition of whey to clay soil had an insignificant effect on the harvest weight of corn seedlings but reduced yields 30% for loam soils. However, intermediate amounts of milk and whey produced a slight increase in seedling harvest weights. The addition of whey to sand decreased the plant weight to 17% that for water alone and mixtures of milk and whey decreased the yield but not as dramatically as for whey.

In their study, Lawton et al. (612, 613) found that sodium ions tended to accumulate in the first six inches and sometimes the first 12 inches of soil. The parts per million of sodium in the top surface layer was about 130, 210, 450, 150, and 143 for plants A through E, respectively. The corresponding sodium contents at a depth of 24 to 30 inches were 41, 50, 110, 110, and 110, respectively.

Other Experiences with Dairy Wastes

Magnusson, F. (647) reviewed the State of the Art of spray irrigation of dairy waste waters with special attention to the applications in French, German, and the Scandinavian countries.

Walgren and co-workers (1201, 649) have recently reported on their investigations concerning irrigation with dairy waste water. Water from the Harlosä Dairy in southern Sweden was irrigated for three seasons (April-November). The application rates were 56, 102, and 30 kilograms per hectare on a daily basis for dry matter, 24, 27.3 and 13.2 kilograms BOD per hectare on a daily average with total irrigation amounts of 17, 100, 31, 200, and 19, 100 cubic meters total for the 120-day season for equivalent irrigation of 570, 1039, and 637 millimeters on an annual basis. The soil infiltration rate and drainage program and water table amount are not reported.

Soil analysis indicated that the conditions for plant growth on the base of pH and phosphorous content were improved and no direct ill effect was observed on animal health or water quality. Coliform organisms survived one to two weeks depending upon rainfall. The authors caution not to irrigate dairy wastes within 200 yards of build-up areas.

McKee (682) has reported several instances of spray irrigation as well as suggestions for successful operation.

In the first installation in Camden, New Jersey, 75,000 gallons per day of waste was spread on the 45 acres. Unacceptable odor nuisance was attributed to holding the waste five to six days prior to irrigation.

In a second milk processing plant, also making cheese, a waste of 30,000-75,000 gallons per day was applied on three ten-acre fields in rotation. The applications were made daily within three hours. No problems with winter operation have been reported although heavy sheet ice formed on the ground and fences.

A slope of less than 6% was suggested. The month of March was found to be the most difficult period of operation because of alternate periods of thawing and freezing, the ground is normally saturated with water due to the melting snow, the grass has not started to grow, and there is little opportunity for evaporation-transpiration. Consequently, runoff is expected at this period.

McKee reports that experience indicates that spray irrigation systems will operate successfully with considerable higher proportion of whey than can be tolerated in other treatment methods, such as trickling filtration or activating sludge. However, large amounts of whey in the effluent was expected to adversely affect grass growth and promote growth of weeds. Application rates of 2500-10,000 gallons of waste per acre per day were recommended, depending on soil types and vegetation.

Sanborn (916) has reported on the disposal of food processing wastes by spray irrigation. Both Plants B and C pastured dairy cows on the fields after observing the 10-day intervals. No difficulty had been experienced with winter spraying for Plant C. Application rates with good cover crops are suggested at 0.4 to 0.6 inch per hour.

Researchers at the University of Wisconsin and the USDA Eastern Regional Laboratory have made an in-depth study of spray irrigation of dairy waste at five plants in Wisconsin. The early phases of this investigation were reported by Breska et al. (191), a later report is presented by Lawton et al. (613) and the over-all work is discussed in greater depth in a joint agricultural-engineering experiment station report of the University of Wisconsin (612).

Some operational problems were encountered. In Plant B, good drainage permitted retention of the same irrigation plot for the two months during the summer of 1956. However, the grasses were killed during the winter irrigation and did not return before reseeding. Although the ground was level, odor problems were noticed. Consequently, these odors attributed to the development of septic pH draining in the holding tank.

In Plant C, where the wastes were applied all winter, the crop was almost killed completely but did recover. By July, there was no difference between the area covered by ice and that not previously covered by ice. In this site the slope was sufficient to permit some runoff.

In Plant D, where the silt loam was underlain with a fairly tight clay, runoff occurred almost every day shortly after irrigation had begun.

A number of the plants in the study of Lawton et al. (612, 613) had alternate means of winter disposal other than irrigation. These methods included use of septic tanks or dry wells, direct discharge to streams, discharge to roadside ditch, and lagooning. Generally, cooling water was discharged directly to water courses.

The spray irrigation during winter was not entirely satisfactory because of the death of vegetation. This killing of vegetation would require approximately double the irrigation otherwise necessary in order to permit disposal on one section during reseeding. Further precautions are necessary to assure drainage of lines and operation of sprinkler heads and satisfactory operating immediately after startup during winter operations.

Ridge and Furrow Irrigation: Ridge and furrow irrigation uses methods of supplying water similar to the furrow or correlation irrigation used in the West and Southwestern states. The waste is diverted into furrows higher than the main ditch by the use of dams or other structures. The furrows are loaded within a few inches of their tops and then flow is diverted to another area. The furrows or trenches are generally 6 to 15 feet apart, 1 to 2 inches deep and 1 to 3 inches wide. Schraufnagel has reported that the wastes are generally absorbed in less than 24 hours. The negative slope of the furrows should be slight because ponding is reported at lower ends during winter periods.

Contour furrows also have been used with success. Two-thirds of the 35 installations in Wisconsin then using ridge and furrow irrigation were said to be doing a good job (952). Insufficient land area, low infiltration rates, high water table, odor, and poor operation are said to be responsible for the defects found in the upper third of the installations.

Schraufnagel (951) discussed the factors influencing the quantity of waste water which may be applied. The quantity is said to be dependent upon the soil type, drainage, crops, and climate.

Sands and gravels were said to tolerate much higher loadings than clay and other poorly drained soils. Schraufnagel (951) suggested a maximum consumptive rate of water for purposes of evaporation and transpiration to be about three-tenths (or 0.03) inch per day or slightly over 8000 gallons per acre per day during hot months. This loss was believed little affected by the type of forage crop. Normal evaporation transpiration was said to amount to 3500 to 7000 gallons per acre per day.

Schraufnagel also suggested that the Spring is the critical season with respect to ridge and furrow application for the milk receipts, with the production-market situation then prevailing, were generally high and the infiltration rates were low due to low temperatures and high water tables. In this period, as in the winter months, vegetation cover is minimal so runoff losses are higher and evaporation-transpiration is low.

A rule of thumb figure of 0.01 million gallon per day per acre has been suggested as a design basis (952) for industrial wastes. This rule, however, was said to possibly be in error by four to five times depending upon the soil type. For dairy wastes, the author (951) reported minimum rates on the order of 4000 gallon per acre per day. The use of soil maps and infiltration tests are said to be helpful. A small pilot plant operation is said to be preferable.

Schraufnagel (951) reported that cannery waste experience indicated that waste absorption rate was independent of the strength of the waste. For milk wastes, loading rates were said to vary from twenty-five or less to one documented instance of 2500 PAD of whey over gravel, an abnormal operation which was expected to give difficulties in most systems.

Harding (432) reports that ridge and furrow seepage trench systems initially may handle as much as three to five gallons of waste water per day per square foot of wetted area but often, due to microbial growth, can handle only 1 to 1.5 gallons per day per square foot after one to three years. When the wet sludge (up to 0.4 cubic foot per square foot of trench of a sludge) is removed, odor problems were experienced.

Drainage permits higher loadings and removal of the concentrated salt solution. Such drainage is more necessary for poorly drained soils. Schraufnagel (951) has recommended depths from 2.5 feet to prevent short circuiting, to as much as 304 feet to promote greater vegetation and growth. Drainage at intervals of less than 20 days was said not to be warranted. Tiling at depths greater than 2-1/2 feet below the furrows was said to be usually satisfactory (952) unless the waste has a BOD of more than 1000 ppm. The Wisconsin experience is said (952) to have indicated BOD's of 10 ppm less during the summer unless short circuiting is observed. During winter months and early spring tile BOD's are said to be in the range of 20-50 ppm.

Reed canary grass was suggested as a cover crop because it is permanent, reproduces itself, has substantial root structure and endures water and ice coverage well (951). Rome or Kentucky grasses were not as well suited because of poor water ice cover endurance.

The nutrients provided from an installation with a processed 0.1 MGPD product and a 1% loss would have a fertilizer equivalent of 15 pounds per day of 10-12-15, i.e., nitrogen-phosphorous pentaoxide-potash.

Schraufnagel (951) has reported on the ridge and furrow treatment approaches at several Wisconsin installations.

The first plant was the Moliand Creamery which produced market milk products and butter. The disposal area contained approximately 2.75 acres and was relatively flat. It was divided into three sections by means of check dams and was underlain with one line of drain tile. The infiltration rate in the clay loam is one inch in 33 minutes, with an effluent of 0.05 MGPD and an estimated BOD of 210 ppm. Approximately 90% BOD reduction was reported. A small grease trap was used; odors have not been sufficient to cause complaints.

The Mindoro Cooperative Creamery made butter and occasionally operated as a receiving station. The irrigation area was approximately three acres and was divided into three nearly equal parts which are underlain with two lines of drain tile perpendicular to the furrows and

2-1/2 to 3 feet underneath them. Approximately three fourths of the disposal area was in grass, the remainder being trenches and headers. A detention period of three days was estimated. The soil was believed to be a Toddville silt loam. Infiltration in the unused areas indicated a seepage rate of about one inch in 18 minutes with a waste concentration estimated to be 300 ppm BOD. The loading is estimated to be 312 tons/year or 58.3 pound BOD per acre per day. A small flow, estimated at less than five gallons per minute, has been found from the drain lines from about November to May, varying in strength from 25-50 ppm. No significant odors have been reported.

The Barneveld Swiss Cheese factory utilized three ditches, each 3 feet wide, 3.5 feet deep and 75 feet long, in rotation for disposal. Odors were sometimes noted but were attributed to accidental whey discharge.

The Hillside Dairy, which processed 30-71 TP of milk for cheese used a 1.75 acre plot divided into three sections with a distribution ditch in the center. The soil was essentially gravel, and about 40,000 pound per day of whey was successfully discharged. The field was about eight to ten feet above the stream level.

The Dairy Maid Cooperative, a butter and dried by-products plant, irrigated three sections in which the soil consists of clay loam over white sand. The hydraulic load on the 4.6 acres was about 17,000 gallons per day.

Clifton Farmer's Cooperative Creamery used three plots, the largest of which was underlain with two lines of drain tile. Flooding has been observed in the winter. Ground water was near the surface at the time of the installation of the system.

The Lafayette Cooperative Creamery disposal system, which consists of two fields, was laid out on sandy loam. The furrows were an average of 2 feet by 18 inches, approximately 6 feet center-to-center. Drainage was not used.

The Farmer's Cooperative Creamery Association system was used only during the period from freezing time to April 15 or May 1. Spray irrigation was used during the warmer months. The soil was a heavy clay with some gravel streaks. Tile lines had been put in for drainage.

The Sherry Dairy Treatment system consisted of a main ditch, and eight perpendicular lateral ditches two to three feet deep. This disposal field was about four feet above the normal level of an adjacent creek. Poor infiltration was noted during the periods of high water level; one summer, scum was noted in all of the ditches.

The Garden Valley condensery used ditches every 10-15 feet. The disposal area had a 0.57 inch slope, sandy soil and good drainage above it, so drain tiling was not used. Pooling at the low end of the furrows had been reported.

The Modena Cooperative Creamery used a herring bone distribution pattern. The soil was Waukegan silt loam, sand and gravel below three feet. Drain tile was not used. Schraufnagel (951) has reported that at the Moland Creamery where the tile drain discharge is about equivalent to the waste volume the treatment efficiencies were usually in the order of 98-99%. In the Mendoro facility, the author estimates that the discharge to the creek gives reduction of over 80%. At still another installation one winter flooding decreased the BOD efficiency as measured from drain tile effluent to about 50%.

Odors are a potential problem with ridge and furrow irrigation. Schraufnagel (951) has suggested that control can be maintained by reduction in waste concentration and by diverting cooling water to the treatment system. Treatment fields at least 500 feet from the nearest residence were suggested. Grease traps were suggested to avoid soil blockage, and the consequent ponding leads to malodors.

Schaufnagel also compared spray and ridge and furrow approaches. The spray irrigation systems were said to be of (1) lower cost, (2) have less danger of nuisance, (3) require no land preparation, (4) be easy to expand, (5) be easier to crop, and (6) be more suitable for woodland and hill slopes than for ridge and furrow irrigation systems. The ridge and furrow systems are said to have the advantages that they (1) require less land, (2) are cheaper to operate and maintain, (3) have less difficulty with winter operation, (4) have less problem with removal of gross solids, and (5) may or may not require pumping.

Performance Data

Available performance data for spray irrigation, ridge-and-furrow irrigation and the Lawton (612, 613) spray irrigation study are summarized in Tables 99, 100, 101. Rationalization of these reports is difficult due to the fragmentary reporting of the rates of moisture loss and not distinguishing between maximum application rate, infiltration rate, and cumulative utilization.

Comments on State of the Art of Irrigation

The influence of BOD loading for various soils and air availability appears to be a void in our basic understanding of waste disposal by the irrigation process. BOD loading, however, is not completely uncoupled from hydraulic loading for increased hydraulic loadings decrease the aeration of soils with poor drainage characteristics.

Relatively little quantitative work has been cited in the waste disposal literature on the loss in permeability due to the buildup of lactose-based polysaccharides and other microbial flora products. Particularly needed are approaches for regenerating the infiltration capacity for agricultural land disposal.

Table 99 - Performance Data for Spray Irrigation Systems

Process	Amount Processed	Soil Type	Rate of Application	Land Used, A	Pounds BOD Acre/Day	Waste Water MGPD	Remarks	Reference
-	-	-	< 11.8 in 7 mo.	-	-	-	Baltic. 0.6-0.8in./day max.	60
-	-	-	-	-	-	0.158	BOD 6,000-10,000 mg/ℓ Spraying, lagooning, activated sludge, give final effluent 10/mgℓ, Czech.	102
W.H. Ararat Farms Dairy	-	-	< 1.35 in./day	-	-	.004-5	Maryland. 0.5 in./hr infln., 0.35 in/hr appln.	123-124
Willow Farms	-	Galnela silt loam	< 1.5 in./day	6.5	-	.03	Maryland. 0.5 in./hr, 0.35 in./hr	"
Hadley Dairy	-	-	< 0.85 in./day	2	-	.008-10	Maryland. 0.4 in./hr, 0.2 in./hr appln.	"
Losten's Dairy	-	Metapeake loam	< 0.90 in./day	-	-	.004-6	Maryland. 0.5 in./hr infln., 0.25 in./hr appln.	"
Maryland Coop.	-	Unknown	0.5 in./day	-	-	.0015-19		"
Dairy Waste at Heeten	-	Sandy soil	33.5 in./yr	-	-	-	Soil became swampy, the yield and quality of grass decreased. Sprayed only during growing season.	134
Dairy Waste at Tijnje	-	Peat soil	15-20 in./yr	-	-	-	High yield grass, good quality, mineral balance less favorable. Control by amt. of waste-avoid high load of K & P.	"
Dairy Waste at Jubbega	-	Sandy soil	8-12 in./yr	-	-	-	Same as above. Slight pH increase of soil in all 3 cases. Improvements by sprinkling larger area of land.	"
Whey Wastes	-	-	-	-	-	.005-.007	Total vol. depends on soil permeability & rainfall. Damage to pasture result of overdosing.	302
Whey and Milk Washings	-	-	-	34	-	0.06	1/3 Whey, 2/3 Washings Dil. with 5 times vol.	367
-	-	-	.006	-	-	-	Hyd. load not limiting, org. load is, closed soil pores. BOD > 500 ppm	428,9
Dairy Plant Millingen, Germany	20,000 liters	-	-	30	-	.001 - .002		449
-	-	-	-	-	-	-	2.47 A is required/2,200,000 milk processed.	143
Bottled Milk,	-	Heavy soil, well drained	-	30	-	0.8 GMGPY	22-day interval.	147

Table 99 - Continued

Process	Amount Processed	Soil Type	Rate of Application	Land Used, A	Pounds BOD Acre/Day	Waste Water MGPD	Remarks	Reference
Dairy Waste for 3 Factories	10,000-30,000 lb/day	-	0.112 in./hr	-	152	0.0011	Disposal areas are 0.5 to 3 acres.	191 SA 612-3
	20,000-47,000 lb/day	-	.286 in./hr	-	134	.0056	Applied for .75-24 hrs. each	"
	6200-15,000 lb/day	-	.130 in./hr	-	122	.00076	925 to 3680 ppm BOD_5	
10 Dairy or Cheese Factories	-	-	-	10-15	-	-	France. 0.004-.005 MGPD/2-5A	215
Tennessee Swiss Farms	-	-	.11 in./day	2A	167	.012	660 ppm BOD. Pasture	282, 612 682
Ohio	-	-	-	40	-	.40	Winter operation	607, 612
Fort Wayne, Ind.	-	-	.17 in./day	40A	-	.070		607, 916 [sic], 612
New Zealand								
Whey	-	-	6,000/A	-	-	-		677
Lactic Casein Whey and Washings	- -	- -	12,000/A + 20,000/A	- -	- -	-		" "
Dairy	-	-	27,000/A	-	-	-		"
Canadian (Berwick, Ont.)	-	-	-	3	-	.008	Digester for winter	680, 682
Tennessee, (Alexandria)	-	-	-	3.5	-	.012		"
Kentucky (Owenton)	-	-	.003 MGAD .0060 "	winter 6 summer 6	-	-	Winter required drainage of lines, slope, runoff.	"
Indiana Dairy	-	-	.0025 "	-	-	-	Weeds Increased P.	680
Indiana Whey	-	-	.0033 "	3	-	-		"
Tenn. Donaldson	-	-	.0063 "	2	70 lb BOD/day	-	10 days internal	681
Dairy	-	-	.0016 "	-	-	.075		"
Dairy	35,000 lb milk daily 1000 lb cottage cheese/wk	-	.0025 "	30	-	.075		"

Table 99 - Continued

Process	Amount Processed	Soil Type	Rate of Application	Land Used, A	Pounds BOD Acre/Day	Waste Water MGPD	Remarks	Reference
Shirley, Ind.	-	-	0.008-0.009 in./day	10	-	.15	Tiled, 3000 gal/AD. Whey 5000 gpd/30A	420, 680, 682, 612
Alexandria, Ind.	-	-	.03 in./day	30A	-	.018		420, 680, 612
Milan, Wis.	-	-	2400 gal/day	2.5	-	.006		682
Acid Casein Whey	-	Krasnozem, red to clay loam	-	1 14	-	-	Grass cover. 1 vol whey: 2.5 vol wash water. Max appl. 3000 g/A hr 1-22, av. 5 in./A month, Trial A; 1.5-6.5 in./A month, Trial B. 5400 ppm ss.	712
Creamery Effluent	-	-	-	37	-	-	1000 gal. with about 60 gal/milk in it.	910
Dairy Plant	80,000-90,000 lb Milk/day	Light sandy	.15 in./day 560 mm/yr	45	250-350 ppm	.075	Also dairy barn waste from 130 cows 45 min.in. septic tank. Southern N.J. Waste sprayed on alternate days only. 35% cover.	916, 612, 682
Bottling	28,000 lb	Clay on gravel	2.85 in./day	100	-	.08	Southern N.J. Sprinklers moved daily 10% cover. No difficulty winter	916 607
Whey Processing Industry	-	-	5,500,000 lb whey/mo	6,1	-	-	1 mo. applied 5800-70,000 lb/day A--9 days. S; 5.10 in./acre cumulative Safe max. load level is 50 T/A max. per year.	991
Whey Processing Industry	-	-	145,000 lb/day	10	-	-	45 consecutive days. 326 T whey/acre.	991
Large Creamery & Cheese Manuf. Plant	-	Sandy soil	2000 T/A	6	-	-	Whey accum. in low areas resulting in large maggot population. Destroyed in time. Crusting of soil developed. Ridge and furrow.	"
-	-	-	-	-	-	-	Binding soil at the surface probably due to polyuronic acids. Whey imp. soil aggreg, stim. root growth. Increase in K, Mg. P. stim. eff. upper 10-15 cm of soil. Loss water from sand ret. nitrate and red. Ca & Mg of plant. Organic whey N readily converted to nitrate N.	1107, 999
-	-	-	-	-	-	-	Dosage not over 5000 gal/acr/day, although short rate many times this. Cover crop, grass.	1242
Harlosä	-	-	570 -1039mm/yr	-	-	.012 -.023MGD	April-Nov. only. Appld. Twice normal rainfall	1201

Table 100 - Operational Characteristics of Five Spray Irrigation Systems (after Lawton, et al., 191, 612, 613)

	Plant A	Plant B	Plant C	Plant D	Plant E
Milk Intake (lb/day)	20,500	20,000	33,500	10,600	13,500
Waste Volume (gal/day)	4,300	1,770	5,900	1,135	380
Acres Irrigated					
1. Total	0.97	0.65	1.15	0.213	0.018 (run off)
2. Each Setting	0.194	0.216	0.33	0.213	0.006
Application Rate (in./hr)	0.13	0.20	0.23	0.16	2.3
BOD Loading (lb/A/day)	322	295	139	212	675
BOD*	1752 860-4740	4310 1980-9100	936 400-1620	4790 1849-9440	1280 435-2220
COD*	-	7800 3740-15320	1241 366-1880	4520 1467-11500	1703 552-2830
pH	- -	4.8 4.2-5.7	6.4 4.1-8.7	5.6 4.0-7.2	6.8 4.6-9.5
Suspended Solids* Total	-	1040 600-1940	619 220-1980	1025 510-1800	361 273-502
Suspended Solids* Volatile	-	910 500-1840	561 220-1720	998 488-1540	303 200-390
Na ppm	166 103-216	374 202-642	433 98-675	255 168-320	470 183-796

*Values are given in parts per million
Upper values = average
Lower values = range

Table 101 - Performance Data for Ridge and Furrow Irrigation

Process	Amount Processed	Soil , Type	Rate of Application	Land Used, A	Pounds BOD Acre/Day	Waste Water MGPD	Remarks	Reference
Not Given	-	-	0.020	-	-	-	Practiced rather extensively in Wis. and Minn. Operative in wintertime.	683
Mission Dairy Phoenix, Ariz.	-	Tight, uniform	-	10	-	0.06	Eight furrows; filled, 12 hr. Plowed under every other day.	952
Creamery Minn.	40,000 lb/day	-	-	2.8	-	-	Three sections, tile (one) 3 ft. Eff. BOD 3 ppm, 210 ppm disch.	"
Mindoro Creamery Wisc.	50,000 lb/day	-	.023	3	300 ppm 58 lb/AD	.03	One half land used a time. Two lines of tile. Max BOD in drain tile 49 ppm.	"
Moland Coop Creamery	49,200 lb/day	Clay loam	.012	2-3/4 / 2	210 ppm	-	Drain, cooling, 1.8"/hr inf., sprayed weeds	
Claremont Creamery								
Claremont Creamery Claremont Creamery	167,000 lb/day	-	.004	7 / 5	-	-	Drain, no CW 1.8in./hr inf.	
Farmers Coop Creamery	-	Heavy clay	-	5 / 5+	-	-	Drain, winter only, 3.3in./hr inf.	
Mindoro Coop Creamery	48,600 lb/day	Toddville silt loam	.023 .85in./day	3-1/2 / 1½	300 ppm	- -	Drain, CW 3.3 in./hr inf.	
Garden Valley Coop Creamery Co	50,000 1lb/day	Sandy silt loam	.020	1-1/2 / 1½	-	-	No drain, good head to W.T., pooling	
Modena Coop Creamery	24,700 lb/day	Waukegan silt loam	.015	1-1/2 / 1	-	-	CW 3 ft. head to W.T.	
Sherry Dairy	25,000 lb/day	-	< .003	1/2 / ½	-	-	Drain, no CW, scum, 4 ft head to W.T.	
Barnveld Swiss Cheese	15,000 lb/day	-	.004	1 / ½	-	-	Odors (3'x3.5'x225')x#3	
Clifton Farmers Coop Creamery	40,000 lb/day	-	.006	3 / 3	-	-	Drain, C.W. high W.T.	
Dairy Maid Coop	170,000 lb/day	Clay loam, white sand	.004	4.6 / 4.6	-	-	Some winter flooding	
Hillside Dairy	50,000 lb/day	Gravel	> .020	1-3/4 / ½	-	-	Cooling water, 8 -10 ft head	
Tilden Creamery	46,500 lb/day	Sandy	> .022	3.6 / 1.8	-	-		
Lafayette Coop Creamery	25,000 lb/day	Sandy, loam	-	1.4	-	-	2x1.8x6 ft 6 Drain	
Hoffman Corners Coop	32,000 lb/day	-	-	2-1/2	-	-	Drain	

Table 101 - Continued

Process	Amount Processed	' Soil Type	Rate of Application	Land Used, A	Pounds BOD Acre/Day	Waste Water MGPD	Remarks	Reference
Farmers Coop Dairy Assn.	79,000 lb/day	Painfield Sand	.032	1-1/4 /3/8	-	-		
Dairy Wastes	-	-	-	-	-	-	Furrows 1 ft wide, 16 in. deep, ridges 5-8 ft wide	1257
-	-	-	-	-	-	-	Only 1/2 to 1/3 should be used at one time. Reed's canary, fescue, orchard grass satisfactory	1258
Dairy Wastes Briar's Dairy	-	-	-	-	-	0.024	Trench- 800 ft^2, 3 gpd/ft^2 absorption	1273

Also relatively few studies of the kinetics of utilization of milk-like wastes by the microbial flora of the soil alone or of the residence time distribution such as would be required for the interpretation of irrigation in terms of our current understanding of trickling filters are found.

Comparatively few studies have been concerned with evaluating the actual performance in some quantitative manner. Fields have infrequently been underlain with tile and, if so, rarely have the tile effluents been monitored. Except in areas of deep percolation, Tiling, system monitoring and lagoon capture may be desirable. Only infrequently have contributions to streams been approximated by measuring upstream and downstream concentrations and volumes.

It should be possible to make a materials balance on soil systems by monitoring what goes in, what goes out, and the accumulation of materials at various levels. Operators should log rainfall, estimated crop use and material applied as big irrigation schemes do on a regular basis. Both short term and long term aerated storage capacity are required to permit operation in periods of high rainfall, or low permeability and usage (as in the winter). Lagoons may be a possible storage means.

There is little indication that lands with slight slopes have collection ditches to divert runoff or tile effluent to some kind of lagoon to prevent direct entry into streams or other areas. Diversion dikes are needed to reduce rain loadings of irrigated land.

Some of these steps appear to have been done with ridge and furrow irrigation as reported by Schaufnagel (951).

Odors have generally been attributed to the development of anaerobic conditions in the holding tank prior to irrigation, ponding in areas of poor drainage and to frozen soil in the spring thaw.

Most of these reports were made a decade or more before the public became sensitized to environmental problems and odor nuisances. In this decade a substantial portion of the smaller plants which were able to use irrigation economically have gone out of business; others have consolidated. Generally, the larger plants and, in particular, the fluid milk and ice cream plants, have been located in the highly concentrated areas of the deteriorating inner city or the industrial-bluecollar suburban fringe. In these areas land costs are prohibitive. Those plants located primarily on the outskirts of cities are being rapidly encroached upon by housing units and so irrigation systems in these areas are becoming a potential nuisance.

ECONOMICS OF DAIRY FOOD PLANTS WASTE

The cost of disposal of dairy food plant waste is influenced by whether or not the dairy food plant has its own treatment facilities, is utilizing an existing municipal facility and the ordinances and policies of the municipality.

As dairy plants become larger and as the capacity of municipal treatment facilities become limited or marginal and as more stringent requirements come into being in respect to effluents from treatment facilities, there has been an increasing tendency to place an economic responsibility more directly on the dairy food plants. A majority, approximately 90%, of the dairy plants in this country utilize municipal treatment facilities. As cities become more sophisticated and recognize the significance of the dairy food plants to their BOD and COD load, there has been a trend to either (a) charge the dairy food plant a surcharge on BOD, COD, suspended solids or other compositional factors that is above the concentration normally present in domestic waste or (b) arbitrarily limit the composition of the waste that can be discharged to the city system.

Effects of Limits on Waste Composition Going Into Municipal Treatment Plants

Several communities in this country, to meet imposed stringent stream standards for BOD or to permit proper plant operation, have passed ordinances prohibiting the discharge of whey, placed a limit on BOD and/or other components such as free lipids (hexane solubles) and/or suspended solids. These limits have been based on domestic waste values and have generally been formulated in terms of a ppm strength rather than an absolute quantity. Generally the limits set to date have ignored the quantity of waste water and focused only on the ppm strength. It would appear to be more logical to take into consideration both waste water volume and per unit volume strength and to establish standards on the basis of coefficiency strength, such as the total pounds of BOD per day or the total pounds of free lipids per day.

Where limits have been set for the BOD at 200-250 ppm, dairy plants have been forced to either move their operation or to install their own pre-treatment facility. With current technology, eliminating all possible sources of BOD through various control procedures, it would appear that 400-500 ppm is the lowest achievable unit volume strength that can currently be obtained. As more and more cities impose such standards, there will be an increasing demand to install pre-treatment facilities in dairy plants. The need for such standards on effluents to municipal systems needs very careful study. During the course of this investigation there was an occasion to work with one dairy plant facing a limit in its BOD and suspended solids of 200 ppm to be achieved within 18 months. This plant, manufacturing milk and cottage cheese, produced about 1000 pounds of BOD per day at a concentration of 2000 ppm, if whey was excluded from the waste water. Using all the methods outlined earlier in the report for conservation resulted in a reduction to 550 ppm. They considered using dilution to bring the BOD down to 200 ppm limit but finally decided to install a treatment facility which will be under construction shortly. This same problem will be facing dairy food plants increasingly in the next five to ten years. As more demands for the development of waste treatment facilities are made by dairy plants, there will be a need to develop more basic information and more efficient treatment systems for fluid dairy plant waste.

Effect of Surcharge on Waste Composition

Another approach being used increasingly is to charge a cost to the dairy foods plants for the components of its waste above the values excepted for municipal waste. These charges vary widely and costs involved in terms of BOD, and suspended solids are calculated from a variety of formulas. Representative formulas are as follows:

1. Surcharge = 0.9 x BOD in ppm ÷ 250 x 8.34 x gallons of waste water x the rate for water usage.

2. Surcharge = ($0.023 per 1000 gallons x 0.014 x lb/BOD_5) + (0.023 per 1000 gallons x 0.024 x lb susceptible solids) - ($0.004 per employee day work) - (10,000 gallons x 0.023 + lb/BOD in 10,000 gallons x 0.014) + (lb suspended solids in 10,000 gallons x 0.024).

3. Surcharge = B + C - D + E where B is the cost factor for total suspended solids above established minimum of 250 ppm. C is the cost factor for oxygen demands in excess of 250 ppm BOD or COD; D = the cost deduction factor for that portion of water that goes into the manufactured product or its production by-products or is disposed of by other means than the city sewers; E is the added cost factor for properly metered private water ultimately discharged to sewers, with the cost being determined of $0.02 per lb. for BOD_5 above the 250 ppm + 2.0 x lbs. of suspended solids above the 250 ppm limit.

4. Surcharge = (suspended solids in ppm - 350 x 8.34 x F x 182.5 x 0.95 x 40)/2000 + (ppm BOD - 300 x 8.34 x F x 182.5 x 0.95 x 45)/2000 where 350 is is the total suspended solids in normal sewage, 300 is the BOD in normal sewage, 8.34 is the weight per pound in a gallon of water. F is the million gallons of waste water per day; 182.5 is the number of days for each semiannual period; 0.95 is the factor allowance for 95% purification;

40 is the surcharge in dollars per ton of excess suspended solids ($0.02/lb) and 45 is the surcharge in dollars per ton of excess five-day BOD ($0.025/lb).

5. Surcharge = $0.0129 x (ppm BOD_5 - 300) x gallons x 8.34 + $0.21 per 1000 cubic feet of water consumed.

6. Surcharge = a fixed monthly rate x (parts per million BOD - 250) x 0.0025.

7. Surcharge = 1.5 x dollar value of water bill + $0.01/lb BOD and $0.01/lb suspended solids in excess of 250 ppm.

On the basis of BOD surcharges, the communities from which information was obtained vary in their rate of surcharge for BOD and suspended solids from $0.01 to $0.08 per pound.

In the survey conducted during this study, cost of waste water treatment was available for 20 of the commercial dairy plants. The information is tabulated in Table 102 in respect to the pounds of BOD produced per month calculated on the basis of days of operation per month times pounds of BOD per day, the cost per month in explanation of the charges from which the cost is based. For those plants paying a surcharge the cost ranged from $250 per month to $12,500 per month, which represents costs of $3,000 and $150,000 per year. The plant paying waste water treatment costs of $150,000 per year is paying approximately $0.05 per pound of BOD and discharge over 100,000 pounds of BOD per month; whereas the plant paying $3,000 per year is discharging less than 2,000 pounds of BOD per month and paying about $0.01 per pound. In discussing the differences in the rate per pound of BOD with sanitary districts, they attributed the variation in cost across the country to differences in capital investment, operating costs and the relative load on the plant from industrial sources. In the case of the plant paying $3,000 per year for waste water treatment, it contributes less than 5% of the BOD load on municipal treatment system; whereas the plant paying the largest fee is contributing approximately 80% of the BOD load to the municipal treatment plant.

Costs for plants paying a "cost only on water usage" ranged from $48 per month to $6,300 per month reflecting a marked difference in the cost of water in different portions of the country.

Most of the plants operating their own treatment facilities did not have accurate cost data. In one case where the plant was treating about 80,000 pounds of BOD per month, the cost was $5,500 per month, which included a portion of the capital investment. The discharge from the treatment plant was being treated by the city plant and a charge was being assessed over a given quantity of BOD.

Table 102 - Waste Treatment Costs for Commercial Dairy Food Plants in 1970

Plant No.	Pounds BOD per Month$_L$	Method of Treatment	Cost/Month (1970)	Explanation of Charges
3	20,900	City	$ 958	$5,000 annual cost + $5.12/1000 gpd > 50,000 pd + $1.70/lb BOD > 200 ppm
4	58,600	City	700	1.5 x amount of water bill + $0.01/lb BOD and $0.01/lb suspended solids in excess of 250 ppm
5		City	100	Unknown
6	35,000	City	444	Volume x water rate
7	34,540	Plant Act. Sludge	150	Operating expenses
8	83,600	Plant Act. Sludge & City	5,500	Operating cost and amortization of treatment plant + charge for city treatment
10	21,000	City	262	Volume waste water x 60% water costs
11	4,000	City	6,300	Based on water usage x $53.27/mg % BOD
14	-	City	304	$0.047/1000 ft^3 of water purchased
16	-	City	1,824	$0.23/gallon
19	-	City	48	Based on water usage
	36,850	City	600	Based on water usage
23	34,364	City	5,413	Based on water usage x $53.27/mg % BOD
24	2,574	City	70	Based on water usage
26	-	City	165	Based on water usage

Table 102 - Continued

Plant No.	Pounds BOD per Month$_L$	Method of Treatment	Cost/Month (1970)	Explanation of Charges
27	1,770	City	$ 250	77% water bill (volume x 8.34 x (0.0178/ppm BOD - 250) + (0.0170 (ppm SS-300)
28	19,690	City	1,146	77% water bill (volume x 8.34 (0.0178 (ppm BOD - 250) + (0.0170 (ppm SS-300)
30	134,860	City	5,416	Water rate + 0.025 (ppm BOD-250) + (ppm SS-300) x gal x 8.34
31	62,200	City	2,916	90% water bill x 0.02 (ppm BOD-250) + (ppm SS-300)
51	64,800	City	3,000	Water rate + 0.02 pound BOD over 200 ppm + 0.02 pound SS over 200 ppm
57	116,760	City	12,500	Fixed charge (ppm BOD-250) (0.0025) on water usage

Cost of Waste Water Treatment Facilities

Using the value of $0.02/lb BOD as a reasonable mean figure for surcharge, the surcharge cost, which represents only a portion of the over-all charge for municipal waste treatments attributal to plants treating from 100,000-700,000 pounds of BOD per day, is shown in Fig. 70. This figure shows the cost of a normal receiving, filling, pasteurizing and over-all fluid milk plant with a 1.45 pound BOD coefficient per 1000 pounds of milk processed and the cost for a plant operating at a coefficient of 3 pound BOD per 1000 pound milk processed. Figure 71 is a continuation indicating the cost for 5 pound BOD per 1000 pound cottage cheese wash water containing 8 pound BOD per 1000 pound milk processed, and cottage cheese whey containing 26 pound of BOD per 1000 pound milk processed. In many instances the surcharges shown represent only about 50% of the over-all waste treatment charge. In addition to reduction of the BOD coefficient it is equally significant to reduce the water volume.

Cost of Waste Treatment Plant Facilities and Operation

The attainment of actual cost information on the construction and operation of dairy waste treatment facilities is difficult, based in part upon the lack of information in industry and at the same time the contradiction of information available in the literature. Zall (1289) in his investigation, found that only one of 55 food plants visited in 1967 knew waste discharge volumes and only 16 had any idea of cost of waste disposal. In our own survey of 57 plants, only 20 had actual cost figures.

In respect to operations the cost stated in Zall's study for the lowest individual plant per year was $1500 and the highest cost was $25,000. The operating costs were figured on the cost of man-hours expended by part-time labor assigned in the sewage disposal area, the cost of chemicals used in the treatment system, dollar purchases of material to promote digestion and power consumption assigned to electric motors in the waste treatment plant. In Zall's investigation, and also in our own survey information, neither physical size of the food plant nor its annual dollar sales correlated to waste handling expenses. The operating costs for different methods of treatment follows:

Method of Treatment	Dollar Expenditure per year (1967)
Spray irrigation	$ 1,500
Spray irrigation, excluding whey discharge	12,500
Spray irrigation, including whey discharge	15,000
Oxidation pond	1,500

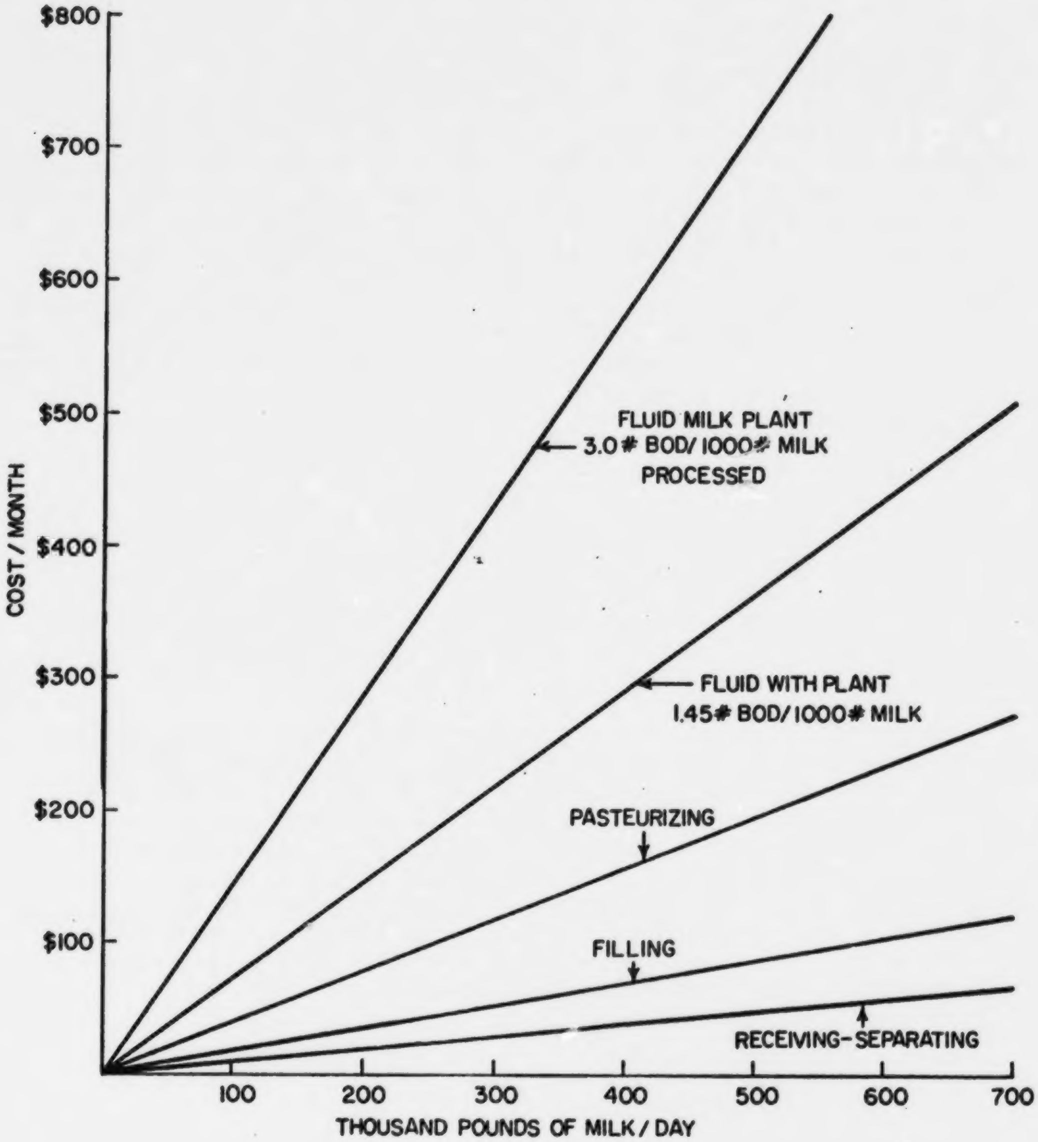


Figure 70 - Cost of BOD surcharge for different standard unit operations and fluid milk with different levels of BOD as a function of milk processed

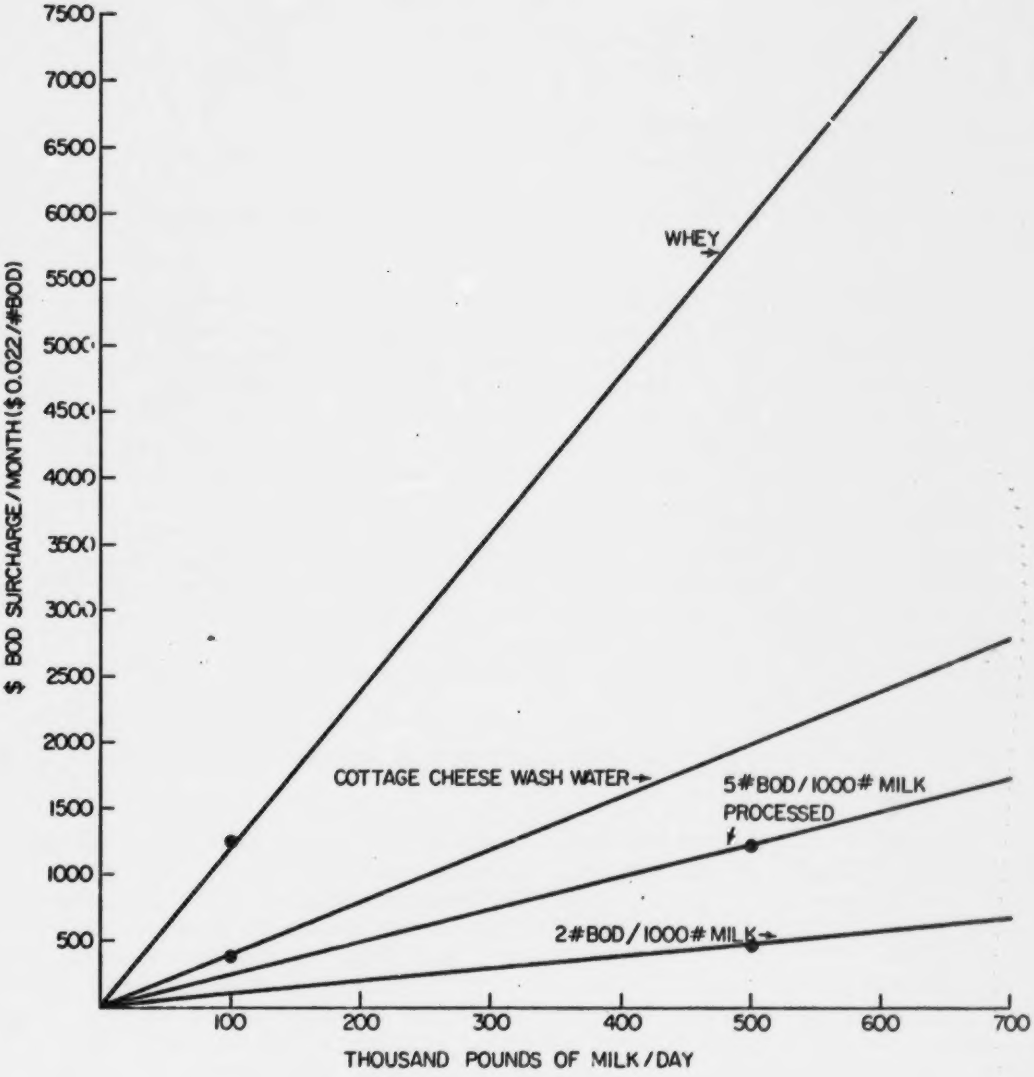


Figure 71 - Cost of BOD surcharge for whey, cottage cheese wash water and fluid milk plants with different levels of BOD as a function of milk processed

Method of Treatment	Dollar Expenditure per year (1967)
Oxidation pond	$10,000
Aerated lagoon	8,500
Activated sludge	10,000
Municipal activated sludge with BOD surcharge	6,000
Municipal activated sludge with BOD surcharge	25,000

The annual operating costs differed widely as noted in our own survey data.

The operating costs found in the Waste Profile 9 study (355) are indicated in Table 103. These are presented for a typical technology large plant in dollars (1966) per thousand gallons of waste water treated. The ridge and furrow and spray costs were essentially the same from plant type to plant type and unrelated to the BOD load. Aerated lagoon costs ranged from $5.12 to $252.88. These costs varied widely between different plants with an apparent general relationship between the pound BOD per 1000 pound waste water and the cost of operation of the aerated lagoon, which would reflect the cost of oxygen incorporation which should be larger as the BOD loading per unit volume increases. In respect to trickling filter operations the costs range from $121 to $1,024, and appeared to be unrelated to the type of operation or BOD load per unit volume. The same observation is generally true in respect to the activated sludge costs which ranged from $80 to $682 a month.

Treatment Facility Costs: The information on capital costs is somewhat confusing also.

An accurate assessment or development of the universally applicable formula for determining the capital operating costs of dairy food plant waste treatment facilities are difficult because of contradictory information, limited nature of the data available and major differences in the relative costs involved in treatment facilities in different parts of the country. Labor costs, construction costs and land costs are major contributing factors to variability. Information presented in the literature in respect to capital and operating costs of dairy food plant waste water treatment facilities in terms of 1000 pounds of waste water per pound BOD are presented in Tables 104 and 105. As noted, the most complete presentation of cost figures, those in Waste Profile 9, appear to be higher in their estimations of cost than almost all other reports and appear to be based to a large degree on the early work by the U.S. Department of Agriculture and the University of Pennsylvania.

Table 103 - Operating Costs for the Installation of Various Treatment Methods for Dairy Food Plant Costs (1966 Dollars) (355)

Method	$/1000 Gallons of Waste Water Treated				
	Butter	Cheese	Condensed	Ice Cream	Milk
Ridge & Furrow	59.50	73.17	68.20	67.94	54.56
Spray Irrigation	163.35	219.50	192.66	192.30	133.20
Aerated Lagoon	98.48	243.90	18.16	5.12	252.88
Trickling Filter	170.60	1024.39	121.10	291.02	194.12
Activated Sludge	44.61	682.92	80.73	192.44	128.31
Pound BOD/1000 Gallon Waste Water	9.32	16.1	1.45	0.39	25.5

Table 104 - Cost of Dairy Food Plant Waste Water Treatment

Type of Treatment Facility	Lb/1000 Gal Waste Water	Capital Cost/Lb BOD	Dollars Operating Cost		Year	Ref.
			$/1000 gallons	$/Lb BOD		
Spray Irrigation	123	428.22	--	--	1951	916
Trickling Filter	1312	875	0.66	0.44	1955	591
Activated Sludge	1717	1145	1.23	0.82	1955	591
Extended Aeration	223	149	0.27	0.18	1955	591
Activated Sludge	300	200	0.08	0.055	1957	1287
Activated Sludge	300	200	0.10	0.07	1957	1287
Spray Irrigation	109	73	--	--	1961	677
Aerated Lagoon	279	186	0.30	0.20	1963	936
Trickling Filter	225	150	8.74	5.83	1964	1023
Trickling Filter	397	265	--	--	1965	739
Ridge & Furrow (condensed milk)	392	261.71	3.2	2.12	1966	355
Spray Irrigation (condensed milk)	1107	738.28	9.09	6.01	1966	355
Aerated Lagoon (condensed milk)	30	19.86	0.84	0.56	1966	355
Activated Sludge (condensed milk)	1113	742.06	3.91	2.51	1966	355
Trickling Filter (condensed milk)	1671	1114.48	5.66	3.77	1966	355
Oxidation Pond	126	84	0.06	0.04	1967	698
Trickling Filter	394	263	--	--	1967	740

Table 105 - Capital Cost for the Installation of Various Treatment Methods for Dairy Food Plant Costs (1966 Dollars) (355)

Method	$/1000 Gallons of Waste Water Treated				
	Butter	Cheese	Condensed Milk	Ice Cream	Milk & Cottage Cheese
Ridge & Furrow	344.59	376.34	309.81	379.48	300.10
Spray Irrigation	964.18	1064.51	1071.55	1070.51	894.94
Aerated Lagoon	578.51	1118.27	100.91	28.20	1406.08
Trickling Filter	1487.60	5053.76	675.22	1615.38	1080.79
Activated Sludge	716.25	3365.59	499.54	1076.92	718.78
Lb BOD/1000 Gal Waste Water	9.32	16.1	1.45	0.39	25.5

The other values, when corrected to current costs, appear to be in general agreement around the world and are in agreement with information obtained from consulting organizations who have had experience with the construction of dairy food plant waste treatment facilities. Based on information obtained from consulting companies in the North-Central state area, the following formulas are suggested as approximate estimates of cost taking into account both hydraulic and organic loading.

Construction Costs

Double aerated lagoon:

$$\text{Cost} = [\$200 \times \text{waste volume coefficient} + \$175 \times \text{BOD coefficient}] \times \frac{\text{gallons waste water}}{1000}$$

A single recirculating trickling filter:

$$\text{Cost} = [\$250 \times \text{waste volume coefficient} + \$200 \times \text{BOD coefficient}] \times \frac{\text{gallons waste water}}{1000}$$

A modified activated sludge system with 24-48 hour retention:

$$\text{Cost} = [\$300 \times \text{waste volume coefficient} + \$275 \times \text{BOD coefficient}] \times \frac{\text{gallons waste water}}{1000}$$

Operating Costs

The current operating costs, exclusive of labor, would approximate 75¢/1000 gallons and 50¢/pounds of BOD for aerated lagoons; $2.50/1000 gallons and $3.00/1000 pounds of BOD for activated sludge; and trickling filter operating at $2.00/1000 gallons and $2.50/1000 pounds of BOD.

The information in respect to the cost of constructing and operating waste treatment facilities for dairy food plants is based on limited and insufficient information for full utility to the industry. At the present time each particular installation will have to be figured according to current local circumstances.

EXPERIENCES OF CONSULTING ENGINEERS WITH DAIRY FOOD PLANT WASTE TREATMENT

To ascertain current opinions in respect to the best methods for dairy waste treatment, new developing methods and possible problems associated with dairy wastes, inquiries were sent to 175 consulting engineering firms advertising in the Yearbook of Environmental Science as providing consulting services for waste water treatment. One hundred and six replies were obtained from these inquiries, of which 17 (16%) indicated previous experience with waste treatment facilities for dairy food plants.

The organizations were asked to specifically comment upon their preference for waste treatment methods, their recommendations for the treatment of whey, their familiarity with any new treatment systems particularly applicable to dairy food plant waste handling, specific problems they had encountered in dairy plant waste treatment, and their experiences in respect to the treatment of dairy food plant wastes in comparison to municipal wastes. Personal contact was made with all of the organizations indicating experience with dairy food plant waste treatment. As might be expected, the opinions expressed by the various consulting organizations were varied.

Consulting firms favored the biological oxidation of dairy food plant wastes and indicated the impracticality of other procedures. A common denominator that ran through the comments from all of the organizations was that the best methods of treatment for dairy plant waste would vary from plant to plant depending upon the quantity of waste water, strength, location of the plant geographically, location in respect to major municipalities, the effluent requirements of streams to which the waste waters were discharged, land cost, labor market, local construction costs and availability of adequate treatment facilities by the local municipality.

For small volume, and for BOD effluents below 750 ppm, most organizations favored spray irrigation. For larger plants, recirculating trickling filters in conventional or plastic media were favored by 35%, complete mixed activated sludge by 35%, aerated lagoon treatment by 20% and combinations of these procedures by about 10%. A number of the firms indicated that the combination of trickling filter followed by conventional activated sludge has been useful to meet stream requirements of 20 ppm or less in the BOD of the effluent. Several of the engineering firms indicated that for large plants, processing over 200,000 pounds of milk per day, activated sludge systems produced the best effluent. Several firms indicated that from the standpoint of suspended solids that dairy wastes are easier to treat than municipal wastes. However, it is frequently necessary to provide additional biological treatment to dairy wastes to meet stream standards, which is not necessary for municipal wastes. Several suggested the possibility that detergents could be affecting the efficiency of waste treatment in some biological treatment facilities. Regarding the problems of treating dairy wastes, the following details were cited by a majority of the consulting firms:

1. Difficulty of handling a high waste strength in conventional biological treatment facilities especially if the pH of the waste has been reduced to less than 6.0 due to holding.

2. Problems of shock loading and recommendation for the installation of flow stabilization tanks regardless of the method of biological treatment.

3. Problems with settling of sludge in activated sludge plants was cited as a universal problem.

Other problems included (a) wide variation of flow, wide variation of concentration of contaminates, (b) additional nutrient requirements for biological treatments, (c) extremely high organic shock loads to existing biological treatment systems, (d) quick development of anaerobic conditions in any type of equalization basin, (e) odors resulting from the above-mentioned anaerobic conditions, and (f) a low pH of some waste and a high pH of others.

One consultant stated, "Milk or dairy product spills which occur frequently, can upset the biological treatment system for weeks to months." Other comments included, "Operation and maintenance of independent dairy waste treatment plants are serious problems;" "Detergents used in cleaning dairy plant equipment can upset the process if they are discharged in slugs as is frequently the case. This becomes more serious as water volume control improves." "Aerated holding tanks to blend and more uniformly discharge the waste of treatment facilities are highly desirable, as well as highly shock resistant biological treatment processes." "It is desirable to monitor pH in the flow of the waste treatment plant and to neutralize extremely low pH values by lime or ammonia addition."

All organizations are in agreement in their opinion that whey and the wash water from cottage cheese operations should be excluded from biological treatment facilities.

SECTION X

SELECTED DAIRY PLANT CASE HISTORIES

During the course of this investigation, it has been disconcerting to repeatedly read in the literature and to hear reports of waste treatment systems providing 98% to 99% reduction of BOD on dairy wastes and at the same time not finding this efficiency during site visitations. In none of the dairy plants visited, that had treatment facilities, were these treatment facilities operating properly or entirely satisfactorily on the day of the visit. It would appear from such site visits and from conversation and observation of the daily operations that there is a good indication of rather continual disruption of dairy plant waste facilities from time to time. Where long term data was available, it would appear that the treatment facilities operated below 77% efficiency at least 25% of the time. This suggests a serious deficiency which has been glossed over in the industry. To provide the basis of a somewhat better understanding of the problems facing the dairy industry in respect with wastes and waste treatment, case histories will be presented of four plants: one being a plant in which the waste water volume and the BOD coefficients were numerically less than 0.5, another plant where the BOD and volume coefficients were both in excess of 5.0, a third instance in which the BOD coefficients were approximately 8 and the waste water volume coefficient 2 and a fourth plant which had an intermediate coefficient situation.

PLANT 1

This dairy plant handles approximately 900,000 pounds of milk per day, processing approximately 20% of the product into cottage cheese and the rest into a variety of fluid milk products, including buttermilk and yogurt. The plant belongs to a regional organization which has been concerned with waste treatment and control for over 25 years. Located in a relatively small community, the dairy plant built an activated sludge treatment facility a number of years ago. They identified the sources of major waste volume and BOD early in their work. They determined the BOD of different operations and put into practice conservation procedures after finding they could not discharge whey to the activated sludge plant. At the present time the plant has been automated for fluid processes and CIP and would be classified as an advanced technology plant in all aspects except materials handling. They have taken specific steps to reduce waste water volume and BOD coefficients with reasonable success. The cottage cheese whey is collected and trucked to a drying plant in a neighboring state and the wash water from the cottage cheese is collected and trucked to a site three miles from the plant where it is disposed of by spray irrigation. The milk water mixtures obtained on pasteurization start-up and change-over are collected in a tank and sold as an ingredient for ice cream manufacture. The rinse is approximately 5000 gallons per day containing 3% fat. Two years ago the plant added a double lagoon with aeration of the first lagoon to follow the activated sludge treatment facility in order to meet lowering standards

Preceding page blank

in the effluent going to the waterway. At the present time they are faced with the problem of attempting to meet a four-part per million effluent standard and generally have effluents from the second polishing pond ranging from 10 to 35 parts per million. The waste treatment facility generally operates in excess of 90% efficiency except for periods following accidents in the plant. When these occur the equalizing tank is insufficient to maintain a uniform loading to the aeration tank and subsequently shock loading occurs with some direct discharge going straight through the aeration tank to the clarifier. This results in an upset in the lagoon system and generally requires about a week to re-establish the operation of the treatment facility. Throughout the history of the activated sludge plant, they have had repeated and continuous problems with nonsettling character of the sludge. They have attempted to use flotation, but this was not successfully applied. The operation of the activated sludge facility is based to some degree on imperical approaches and corrections are made on a day-to-day basis. This plant does monitor on a daily basis both the raw influent and effluent from both the activated sludge and the aerated lagoon. The normal efficiency of the two-stage aeration and two-stage clarification system for activated sludge, for the retention time of about 36 hours, results in 75% to 85% reduction BOD most of the time. The quality control people responsible for maintenance of the operation have expressed considerable interest in having some concrete criteria upon which to base design and day-to-day operation of the facility. They do not have any knowledge of the amount of oxygen going into the system, the concentration of solids in the sludge mass, or other common desirable operating parameters.

PLANT 2

This dairy plant handles about 600,000 pounds of milk per day manufacturing both cottage cheese and fluid milk products in a modern plant with automated fluid processing and CIP. This plant has been faced recently with the necessity of making a decision as to how it is going to meet a municipality imposed ordinance that will limit their BOD and suspended solids to 200 parts per million by January 1, 1972. They first attempted to determine the sources of their BOD loads and to do everything possible to bring these down to 200 parts per million. After full identification of all sources, the lowest level they could achieve was 400 parts per million. Therefore, they are investigating the possibility of installing their own treatment facility. They are currently paying a surcharge on BOD and suspended solids of approximately $35,000 per year and anticipate this amount would be doubled if equipment to eliminate a major portion of the wastes and a treatment facility is installed. The treatment of whey in first wash water with reverse osmosis to provide a concentrate can be economically shipped to a drying facility. Installation of storage tanks and automation control to eliminate the rinses from cleaning tank trucks, tanks, and plant equipment, together with the rinses from start-up to shut-down of an HTST unit, segregation of high solid waste from filling operations and returns to truck these out as animal feed, and handling clarifier sludge as a solid waste are all planned as a part of plant control. Investigation was made of the possible feasibility of using a desludging clarifier to recover the fines of cottage cheese whey on an economical basis. The recovery process was disappointing and the characteristic of the casein fine particles were such that they could not readily be used in current food products. In order to evaluate the situation, they have installed a weir and continuous sampling system so that they are in a position now to continuously monitor on a daily basis their operations.

PLANT 3

This dairy plant processes about 500,000 pounds of milk per day into cottage cheese, ice cream and fluid milk. The plant has been newly built, has all fluid processes automated, and has automated CIP. At the time the plant was built, a contract was arranged with the city for the plant to assist in the construction of a high-rate trickling filter system to treat the plant wastes plus the municipal wastes. The plant was designed for handling a waste of 2500 parts per million from the dairy plant, which proved to be underdesigned by a factor of at least 2. Since this plant provides about 85% of the total BOD, they are paying a surcharge at a relatively high rate of about \$0.05 per pound BOD which currently is costing about \$150,000 per year in waste treatment facility charges. When the plant first opened, shock loading resulted in BOD_5 values of up to 50,000 ppm and suspended solids up to 35,000 ppm parts per million. The first change made in the system was to install a storage tank for whey where whey is collected in the storage tank and discharged to a sewer over a twelve-hour period of time when the plant is not operating. No attempt has been made at this time to eliminate rinses from cleaning of any of the equipment or to take any steps to materially reduce the BOD load. Consequently, at least twice a day the plant shock loads the waste treatment facility and the initial settling tank ahead of the trickling filters generally turn white, with the result that the plant has considerable difficulty maintaining adequate efficiency. The trickling filter system is a two-stage system with partial recirculation of the second stage to the first stage (above 35%). The management of this plant has been slow to meet the challenge of reducing BOD and providing a more complete equalization of its loading. Based on the site visits to this plant, it is estimated that approximately 50% of the total BOD could be removed by eliminating the whey cottage cheese wash water from the waste water and that a further 25% reduction could be made by the installation of good management practices through the utilization of the automated system to recover high BOD wastes for utilization as food or feed.

PLANT 4

This plant processes cottage cheese and fluid milk, utilizing about 900,000 pounds of milk per day in a modern automated fluid process and CIP system. At the time the plant was built, the dairy plant installed its own activated sludge system with the effluent of the system going to a municipal activated sludge and oxidation-pond combination treatment system. The plant was designed to handle, but has never been able to adequately treat, whey and has experienced considerable difficulty even in treatment of cottage cheese wash water. The loading of the activated sludge system is high, averaging about 2500 to 3000 parts per million per day, with occasional shock loads up to 10,000 to 15,000 parts per million per day. An equalization tank has been installed to collect the waste wash water from the cottage cheese operation. At the time of site visit, this plant was operating at an efficiency of about 75% BOD removal and was discharging approximately 2000 pounds of BOD to the city system which had been designed to handle not more than 800 pounds from the dairy plant. As a result, the city system was also badly overloaded and the oxidation ponds were totally anaerobic. This treatment facility has had a sporadic and continuing problem with foaming, nonsettling sludge, and intermittent low efficiencies. Daily data on raw wastes and treated wastes BOD were scrutinized and found that over a five-year period of time the plant did not achieve 70% efficiency at least 75% of the time. The cottage cheese operation utilizes a mechanized washing procedure which results in a large degree of curd shattering and considerable amount of fines going to the waste treatment facility. It is estimated that the fines were contributing about 10,000 parts per million BOD to the waste water. Whenever whey or wash water from cottage cheese operation pass directly to the treatment facility without prior equalization, extensive foaming results. Prior to this report, we had the opportunity to investigate this foam situation and found that it was a stable complex between the major protein of the whey and the cell mass which was predominantly ciliated organisms at that time. During the site visit, the sludge was not settling and laboratory examination indicated that it was of extreme low intensity even when the air was totally removed, and appeared to be a high lipid content. The operators of the treatment facility have tried all of the suggested corrective measures without any success. They have been unsuccessful in the utilization of added ammonia, enzymes, coagulating agents, chlorine, phosphates, or any number of modifications in operating procedures. Based on data by Pipes who determined the microflora of this particular activated sludge treatment facility, it appeared that there was no relationship between the microflora, sludge volume index, or efficiency achieved. Pipes characterized the sludge as varying from pinpoint block to deflocculated to bulking. No sphaerotilus were found in any significant number.

The histories provided on these four plants provide some insight into the problems facing the industry in respect to the high volume, automated processing facilities that are current today and will be more prevalent in the future.

SECTION XI

ACKNOWLEDGEMENTS

This study was conducted by Dr. W. James Harper, Dr. J. L. Blaisdell and Mr. Jack Grosshopf of the Department of Dairy Technology, The Ohio State University.

The authors gratefully acknowledge the cooperation and assistance of many individuals and organizations, without whose help this study would not have been possible.

We acknowledge the assistance and cooperation of the many dairy food companies and cooperatives who provided information for use in this study, with special thanks to those individuals and dairy food organizations that provided the courtesy of interviews and plant visits. The access provided to confidential information was invaluable in assessing the current industrial state of the art relating to dairy food plant wastes and waste treatment.

We thank the staff of the Water Quality Office of the Environmental Protective Agency for their assistance during the course of this investigation, with special thanks to the project officer, Mr. Eugene Harris, and to Mr. George Keeler.

Thanks are also given to those Engineering Consulting firms and to the various manufacturers of waste control and waste treatment equipment that provided technical and economic data for use in this study.

SECTION XII

REFERENCES

1. Abrams, I. M. 1969. Removal of anionic surfactants from liquids. United States Patent 3,232,867.

2. Adams, M. P. 1940. Treatment and control of industrial wastes. Can. Engr., 78:(10)50.

3. Adamse, A. D. 1967. Bacteriological studies on dairy waste activated sludge. Meded. LandbHogesch. Wageningen, 66:(6)1-79.

4. Adamse, A. D. 1968. Formation and final composition of the bacterial flora of a dairy waste activated sludge. Water Res., 2:665.

5. Adamse, A. D. 1968. Response of dairy waste activated sludge to experimental conditions affecting pH and dissolved oxygen concentration. Wat. Res., 2:708-713.

6. Adamse, A. D. 1968. Bulking of dairy waste activated sludge. Wat. Res., 2:715-722.

7. Agar, C. C. 1938. Practical methods of preventing dairy waste nusiance. Sewage Wks. J., 10:115-130.

8. Agar, C. C. 1950. Forum on industrial waste problems-cannery milk, and food products. Sewage Ind. Wastes, 22:(6)776.

9. Agar, C. C. 1950. The effects of the New York state water pollution control law on the dairy industry. Rep. N. Y. St. Ass. Milk Sanit., 1949 pp. 21-22; 24, and 26-28 (1950).

10. Allen, L. A. 1964. Treatment and disposal of effluents. Part 1. Pollution and legal requirements. Part 2. Conventional and other treatment processes. Dairy Inds., 29:(2)90-93, (3)164-168 and 176.

11. Allen, L. A. 1968. The bacterilogy of activated sludge. J. Hyg., 43:424.

12. Amant, P. P., and Beck, L. A. 1970. Methods of removing nitrates from water. J. Agr. Food Chem., 18:(5)785-788.

13. American Public Health Association. 1941-1942. Examination of waste and sewage. American Public Health Association Yearbook, 1968, Supplement to Amer. J. Pub. Hlth., 1942, 32, No. 3.

14. American Society of Civil Engineers. 1955. Experiences with a new type of dairy waste treatment. Proc. Amer. Soc. Civ. Engrs., 81:(847) 1-4.

Preceding page blank

15. Ammon, F. 1952. Can dairy waste waters be clarified? Allg. Fischzt., 76:134.

16. Ammon, F. 1960. Milk trade waste waters and their treatment. Ber. Abwass. Techn. Verein., 11:236-246.

17. Ammon, F. 1967. Dairy effluent. SchrReihe Zentverb. dtr. Molkereifachleute u. Milchwirtschaftler, 38:64-76.

18. Amundson, C. H. 1967. A 1967 solution for Italian cheese whey disposal increasing the protein content of whey. 4th Annual Marschall Invitational Italian Cheese Seminar, Madison, Wisconsin.

19. Anable, A. 1948. Sedimentation and hydraulic classification. Ind. Eng. Chem., 40:50.

20. Anders, H. 1961. Water and waste waters in dairy plants. Molkereizeitung, 15:419.

21. Andersen, K. P., and Poulsen, P. R. 1953. Investigations on the treatment of dairy waste water in septic tanks. 13th Int. Dairy Congr., 3:986-990.

22. Andersen, K. P., Lind, C., and Poulsen, P. R. 1953. Experiments with spreading of dairy waste waters. Investigations of the septic tank treatment of dairy waste waters. Beretn. Forsgm., Kbh., 79:1-51.

23. Andersen, M. E., and Morris, H. A. 1966. The problem of waste disposal. An analysis of systems used by selected dairy plants. I. Spray irrigation systems. II. Lagoon and trickling filter disposal system. III. Municipal waste disposal system. Mfd. Milk Prod. J., 57:(8)8-10, 12, (9)30-32, (10)12-13.

24. Anderson, R., and McCoy, E. 1963. Floc-forming bacteria from activated sludge. Bact. Proc., 8:162.

25. Anderson, W. R. 1941. Symposium on effect of industrial wastes upon sewage treatment plant operation. Milk Wastes. Watwks. Sewer., 88:480.

26. Angerer, H. 1935. Operation and economics of processes of land treatment of sewage. LandwirtschaftsKammer, Hannover, 1-109.

27. Anonymous. 1938. Biochemical process treats dairy wastes. Munic. Sanit., 9:333.

28. Anonymous. 1940. Two-stage filtration: Milk and cheese wastes. Eng. News Rec., 124:810.

29. Anonymous. 1940. Report on operation of activated sludge treatment plant for disposal of dairy wastes at H. W. Walker Co., Somerset, Pa. Surveyor, 97:2506.

30. Anonymous. 1941. New system of treatment of sewage and trade effluents. Alternating double filtration: The process discribed. Surveyor, 100-199.

31. Anonymous. 1941. Michigan Stream Control Commission. Fifth biennial report, 1939-40. Lansing, 1-72.

32. Anonymous. 1941. The treatment and disposal of waste waters from dairies and milk products factories. Tech. Paper. Wat. Pollut. Res., Lond., No. 8.

33. Anonymous. 1942. Indiana uses fire screens for handling industrial wastes. Sewage Wks. Eng. and Munic. Sanit., 13:565.

34. Anonymous. 1942. Milk as effluent. The Lancet, 242: 360.

35. Anonymous. 1942. Ohio River Committee Report. United States Public Health Service Final Report, Appendix VIII of Supplement D.

36. Anonymous. 1942. Regulations for the agricultural utilization, especially by spray irrigation, of dairy waste waters. Landesanstalt for Wasser-Boden-und Lufthygiene. 18:142.

37. Anonymous. 1943. Michigan Stream Control Commission. Sixth biennial report, 1941-1942. Sewage Wks. J., 15:980.

38. Anonymous. 1943. Sewerage and sewage disposal in 1942. Surveyor, 102:83.

39. Anonymous. 1943. Emergency minimum sanitation standards. Publ. Hlth. Rep., Wash., 58:1793.

40. Anonymous. 1946. A manual of water supply, sewerage and sewage treatment for public buildings in Ohio for engineers, etc. State of Ohio, Department of Health, Division of Sanitary Engineering.

41. Anonymous. 1946. Disposal of dairy factory wastes. Aust. J. Dairy Technol., 1:(1)30.

42. Anonymous. 1947. Annual report of the Division of Laboratories and Research. New York State Department of Health, Albany, N. Y., 1-180.

43. Anonymous. 1948. Annual report of the Division of Laboratories and Research. New York State Department of Health, Albany, N. Y., 1-136.

44. Anonymous. 1948. Biological aspects of water pollution. Nature, Lond., 161:874-876.

45. Anonymous. 1949. Synthetic detergents present sewage problem. Chem. Eng. News, 27:(24)1723.

46. Anonymous, 1949. Industrial waste data. Publ. Wks., N. Y., 80:(10) 41-44.

47. Anonymous. 1949. Interim report to the International Joint Commission. Abs. Jour., Am. Wat. Wks. Assn., 42:40.

48. Anonymous. 1950. Big sampling program for the Ohio River. Wat. Sewage Wks., 97:414.

49. Anonymous. 1950. Report of the Water Commission, 1949-1950. Digest of Connecticut administrative reports to the Governor, 1949-1950, 4:356-365.

50. Anonymous. 1950. Dairy waste waters. Industr. lait., Paris, 48:162-165.

51. Anonymous. 1950. Waste prevention in the dairy industry. A Report of the Waste Disposal Task Committee of the Dairy Industry Committee.

52. Anonymous. 1950. Government Institute for the Purification of Waste Waters. Report of work during the years 1948-1949. The Hague. 1-64.

53. Anonymous. 1950. Pennsylvania sets standards for milk wastes treatment. Sewage Ind. Wastes Eng. (Sewage Wks. Eng.), 21:73.

54. Anonymous. 1951. Central states set pace in industrial wastes treatment. Wastes Eng., 22:530-546.

55. Anonymous, 1951. Dairy waste waters. Federation Nationale des Cooperatives Laitieres, 1-96.

56. Anonymous. 1952. Creamery wastes and municipal sewage combined in Imhoff trickling filter plant. Amer. City, 67:(5)131.

57. Anonymous. 1952. Government Institute for the Purification of Waste Waters. Report of work during the years 1950-1951. The Hague, 1-108.

58. Anonymous. 1952. Yeast producer thrives on B_{12}. Chem. Eng., 59:244 and 246.

59. Anonymous. 1953. Dairy effluent plant. S. Afr. Industr. Chem., 7:(6)VIII.

60. Anonymous. 1954. Report from the Research Dairy: Some factors in setting up and working of spraying equipment for dairy waste water. Maelkeritidende, 67:(29)708-710.

61. Anonymous. 1954. Milk processing industry waste guide. Sewage Ind. Wastes, 26:(3)299.

62. Anonymous. 1954. Country town expands its engineering services. Munic. Eng. Sanit. Rec., 131:81-87.

63. Anonymous. 1954. Treatment of sugar juices and waste waters from sugar factories. French Patent 1,007,216.

64. Anonymous. 1955. Spray irrigation at Kraft factory. Can. Milk Ice Cream J., 34:(6)42.

65. Anonymous. 1955. The quantity and composition of waste water from a dairy plant. Off. Org. Koninkl. Ned. Zuivelb. F. N. Z., 47:(49) 867.

66. Anonymous. 1955. The task, status, and methods of the State Dairy Agricultural Waste Water Service (RAAD) at Arnhem. Off. Orig. Koninkl. Ned. Zuivelb. R. N. Z., 47:(49)868 and 871-72.

67. Anonymous. 1955. A simple dairy installation. Off. Org. Koninkl. Ned. Zuivelb. F. N. Z., 47:(49)872.

68. Anonymous. 1955. The typical Dutch aspect of the dairy waste water problem. Off. Orig. Koninkl. Ned. Zuivelb. F. N. Z., 47:(49) 877.

69. Anonymous. 1955. Pollution and the determination of the degree of pollution. Off. Org. Koninkl. Ned. Zuivelb. F. N. Z., 47:(49)879.

70. Anonymous. 1955. What the injunction law states. Off. Org. Koninkl. Ned. Zuivelb. F. N. Z., 47:(49)881.

71. Anonymous. 1955. Limiting of raw material losses economizes on water purification. Off. Org. Koninkl. Ned. Zuivelb. F. N. Z., 47:(59)883.

72. Anonymous. 1956. Research in dairy and poultry industry in Czechoslovakia. Dairy Research Institute of Prague, 1-91.

73. Anonymous. 1956. A collection system for rinse milk and utilization by evaporation. Molk. v. Kas.-Ztg., 7:363.

74. Anonymous. 1956. Electric irrigation performs double duty at Co-op milk plant. Rural Power Pictorial, 18:7.

75. Anonymous. 1957. Stop pollution. Milk Prod. J., 48:(1)16-17, 53.

76. Anonymous. 1957. Two new installations in upstate New York. Milk Plt. Mon., 46:(8)18.

77. Anonymous. 1958. Treatment of combined restaurant and ice cream manufacturing wastes. Sanitalk, 6:(4)18-23.

78. Anonymous. 1958. Special number: Water problems in the dairy industry. Molk. Hiddesh., 12:(30)907-918.

79. Anonymous. 1958. Purification plants for disposal of dairy waste waters. Molkerei - Ztg., 12:915.

80. Anonymous. 1959. Dairy extension includes new effluent plant. Contract Rec., 70:(12)15.

81. Anonymous. 1959. Water recovery plant at a food canning factory. Wat. Waste Treatm. J., 7:372.

82. Anonymous. 1959. The milk and milk products technical advisory committee. Sixth annual report, 1-14.

83. Anonymous. 1959. The microbiology of waste waters and polluted streams. Acta microbiol. polon., 8:1-2.

84. Anonymous. 1959. Biological treatment of dairy wastes. Molkerei-Ztg. (Germany), 13:7.

85. Anonymous. 1960. Dairy Waste Disposal. Svenska Mejeritidn. (Sweden), 52:492.

86. Anonymous. 1960. How whey solids can lift your profit two ways. Food Engr., 32:(9)92.

87. Anonymous. 1960. Rivella -- a new form of whey utilization. Dairy Industry, 25:113.

88. Anonymous. 1960. Whey disposal by heat coagulation. Ind. Wastes, 5:95.

89. Anonymous. 1961. Conference of dairy advisors in Weihenstephan. Dtsch. Molkereizeitung, 82:(42)1509-1513, (43)1540-43, (44)1582-85, (45)1618-19.

90. Anonymous. 1961. Water and waste problems of the dairy industry. Molkereizeitung, 15:905 and 1177.

91. Anonymous. 1961. Disposal of effluent with a high whey content. Water Waste Treatm. J., 8:459.

92. Anonymous. 1961. Spray drying adapted for high-acid whey. Chem. Eng. News, 39:(25)66.

93. Anonymous. 1962. Water and waste water in dairy plants. Molkereizeitung, 16:510, 1243, 1334, and 1516.

94. Anonymous. 1962. Treating milk wastes in deep trickling filters. Wastes Eng., 33:28-29.

95. Anonymous. 1962. Water supply and waste disposal. Dt. Malkereizeitung, 83:1124.

96. Anonymous. 1963. Census of manufactures. Vol. I. Summary and subject statistics. U. S. Dept. of Commerce.

97. Anonymous. 1963. Milk wastes cause orders in ponds. Wastes Eng., 34:(1)25.

98. Anonymous. 1963. Small plants for the treatment of waste waters. Revta. Obr. sanit. Nac., B. Aires, 46:295-298.

99. Anonymous. 1963. Industrial by-products and residues and their utilization in agriculture. Prum. Potravin, 14:(5)225-250.

100. Anonymous. 1964. Government dairy products agricultural wastewater service. Report for the period 1959-1964, 1-76.

101. Anonymous. 1964. Ayrshire county council: Mauchline sewage works. J. Proc. Inst. Sew. Purif., Pt. 2, 182.

101a. Anonymous. 1965. Annual Report of Dairy Research Institute, Prague, Czechoslovakia.

102. Anonymous. 1965. Waste waters from cheese factory. Eaux Ind., 138: III-3.

103. Anonymous. 1966. Annual Report of Dairy Research Institute, Prague, Czechoslovakia, pp. 1-61.

104. Anonymous. 1967. Lightnin areators solve waste treatment problem at at milk processing plant. Wat. Sewage Wks., 114-143.

105. Anonymous. 1967. Aerators solve waste treatment problem. Pub. Hlth. Engng. Abstr., 47:1772.

106. Anonymous. 1967. Annual Report of the Dairy Research Institute, Prague, Czechoslovakia. Prum. Potravin, 19:(6, supl.)1-16.

107. Anonymous. 1967. Annual Report of the Federal Dairy Research Institute, Kiel, for 1966. Kieler milchw. ForschBer., 19:(4)297-382.

108. Anonymous. 1967. Effluent treatment plant. Wat. and Wat. Engng., 71:140.

109. Anonymous. 1967. Government Institute for the Purification of Waste Waters. Annual report 1966. Meded. Rijksinst. Zuiv. Afvalwat., No. 4.

110. Anonymous. 1967. Proceedings of an international study conference on water problems, Paris, May-June, 1967. International Federation of Doctor-Engineers and Engineer Doctors-In Science, 1-362.

111. Anonymous. 1967. Treatment of sugar factory effluents. Sug. Ind. Abstr., 29:269.

112. Anonymous. 1968. Annual Report of the Dairy Research Institute Prague, Czechoslovakia, 1-33.

113. Anonymous. 1968. Effluent and water treatment manual. Fourth edition. Thunderbird Enterprises Ltd., London, 1-278.

114. Anonymous. 1968. Plastic filter media in bio-towers at Norfolk canning factory. Survr. local Govt. Technol., 132:(3974)34.

115. Anonymous. 1968. Purification of dairy waste water in an activated sludge plant at Rue co-operative dairy. Government Research Institute for Dairy Industry, Hillerod, Bulletin 173, 1-22.

116. Anonymous. 1968. Approaches for the reduction of the level of contamination of dairy effluent. Government Research Institute for Dairy Industry, Hillerod, 1091:1-5.

117. Anonymous. 1968. Investigations and experiments on the color of butter. Government Research Institute for Dairy Industry, Hillerod, 1-36.

118. Anonymous. 1968. 28th Annual report. Activities of Government Research Committee of Dairying and Government Research Institute for the Dairy Industry, 1967-1968. Government Research Institute for Dairy Industry, Hillerod, 1-45.

119. Anonymous. 1969. Effluent treatment in practice. Fd. Process. Ind., 38:(456)49-51.

120. Anonymous. 1969. The ultimate in engineered surfaces for biological treatment of wastes. Flocor. Ethyl Corporation Commercial Development Division.

121. Antonie, R. L., and Welch, F. M. 1968. Preliminary results of novel biological process for treating dairy wastes. Paper presented at the 41st Annual Conf., Water Poll. Control Fed., Washington, D.C.

122. Antonie, R. L., and Welch, F. M. 1969. Preliminary results of a novel biological process for treating dairy wastes. Proc. 24th Ind. Waste Conf., Purdue Univ., 3-9.

123. Arbuckle, W. S. 1967. Disposal of whey by treatment of activated sludge and spray irrigation. Cult. Dairy Prod. J., 2:(2)5-7.

124. Arbuckle, W. S., and Blanton, L. F. The development, evaluation and content of a pilot program in dairy ulitization--dairy waste disposal and whey processing. Cooperative Extension Service and Department of Dairy Science, University of Maryland, 1-53.

125. Arnaudi, C., Politi, I., and Colla, C. 1946. Experiments on the production of yeast from sulphite liquor of the cellulose industry. Chem. Abstr., 40:3223.

126. Asendorf, E. 1969. Simple and reliable purification of dairy effluent. Dte. Molk.-Ztg., 90:(25)1210-1214.

127. Ashton, T. R. 1963. Utilization of milk by-products: Cultured milk products. J. Soc. Dairy Ind., 16:68.

128. Ashton, T. R., and Gaster, A. J. 1970. Pretreatment of dairy effluent by the tower system. 18th Int. Dairy Congr., I-E a. 1- 2, 9.

129. Atkin, C., Witter, L. D., and Ordal, Z. J. 1967. Continuous propagation of Trichosporon cutaneum in cheese whey. Appl. Microbiol., 15:(6)1339-1344.

130. Aulio, L., Riekkola, M. L., and Erkama, J. 1969. Carbohydrate and lipid components of activated sludge and waste water. Vesitalous, 10:(3)20-24.

131. Ayers, M. H. 1954. Fats, solids, and dollars. Proceedings Milk Industry Foundation, Plant Section.

132. Baar, J. K. 1962. The use of oxidation ditches for treatment of sewage from small communities. Bull. Wld. Hlth. Org., 26:465-474.

133. Barrs, C., de Graaf, A. E., and Keuning, J. A. 1960. Agricultural and technical aspects of sprinkling dairy effluents on grassland. Proefsta. Akker-en Weidebouw, Wageningen, Publ. No. 14, 1-65.

134. Baars, C., de Graaf, A. E., and Keuning, J. A. 1960. Agricultural and technical aspects of the spraying of dairy waste waters on grassland. Rijks Zuivel-Agrarische Afvalwaterdienst, Arnhem, Publ. No. 14, 1-68.

135. Backmeyer, D. P. 1946. Three industrial waste problems at Marion, Indiana. Sewage Wks. J., 18:584.

136. Backmeyer, D. P. 1947. The effect of whey upon the operation of an activated sludge plant. Proc. 3rd Ind. Waste Conf., Purdue Univ., 310-315.

137. Backmeyer, D. P. 1948. 7th operation report of the sewage treatment and garbage disposal plant, Marion, Indiana, for the year 1947. Sewage Wks. J., 20:1111-1113.

138. Backmeyer, D. P. 1948. Disposal of cheese whey by digestion. Sewage Wks. J., 20:1115-1118.

139. Backmeyer, D. P. 1949. Milk wastes in sewage sludge digestion tanks. Proc. 5th Ind. Waste Conf., Purdue Univ., 411-417.

140. Backmeyer, D. P. 1949. Disposal of condensed milk by digestion. Sewage Wks. J., 21:1076-1077.

141. Baetsle, R. 1956. Problems of potable water in the food industry. Techq. Eau Assain., 10:(119)15-22.

142. Balakrishnan, S., and Eckenfelder, W. W. 1969. Nitrogen relationships in biological treatment process. I. Nitrification in the activated sludge process. II. Nitrification in trickling filters. III. Denitrification in the midified activated sludge process. Water Res., 3:73-81, 167-174, 177-188.

143. Baltjes, J. 1964. Spray irrigation of dairy wastes. Missels Zuivelbereid en-Hand., 70:(17)348-354.

144. Baltjes, J. 1965. Dairy industry effluent. Arnhem, the Netherlands: Rijks Zuivel Agrarische Afvalwater Dienst, 1-56.

145. Baltjes, J. 1969. pH of dairy plant effluents. Off. Org. Koninkl. ned Zuivelb. F. N. Z., 61:(34)781-785.

146. Banister, A. W., and Ellison, R. J. 1948. Designing screen-filter plant for pea and milk wastes. Sewage Wks. Eng. Munic. Sanit., 19:124. 19:124.

147. Barfield, A. 1966. Irrigation solves dairy effluent problems. Dairy Ind., 31:736.

148. Barraclough, D. H. 1941. Recent contributions to the study of industrial waste treatment. Surveyor, 99:147, 205.

149. Barritt, N. W. 1939. Two procovative papers discussed. The respiration of activated sludge: Double filtration. Sewage Purif., 1:256.

150. Bates, D. W. 1963. Waste disposal for milking plant. Hoard's Dairyman, 108:(3)349-378.

151. Baumann, E. 1959. Destruction of separator slime. Molkereizeitung, 80:2062.

152. Baustian, H. 1961. Utilization of whey in cheese factories. Molk.-u. Kas.-Ztg., 12:(1)9-10.

153. Baustian, H. P. 1963. About the waste water disposal in dairy plants. Molk. u. Kas.-Ztg., 14:1585.

154. Beeckmans, I., and Philips. L. P. 1956. Mixing industrial waste waters with domestic sewage. Bull. Mens. Cent. Belge Etude Docum. Eaux, 62:52-59.

155. Beijer, A. 1940. Swedish Patent 92,318.

156. Benedek, P. 1967. New developments in activated sludge process. Advances in Water Pollution Research, Vol. II, 351-363.

157. Bennett, G. F., and Hostman, J. W. 1969. A bibliography of books on the environment: Air, water, and solid wastes. University of Toledo, Dept. Chem. Eng., 1-52.

158. Bennett, G. F., and Kempe, L. L. 1967. Relationship between dissolved oxygen concentration and oxygen utilization rates in activated-sludge waste treatment. Chem. Eng. Progr. Symp. Ser., 63:(78)171-177.

159. Bergman, T., Magnusson, F., and Berglof, A. 1966. The quantity and composition of dairy waste water at a dairy plant, 1958-1961. Meddn sevenska Mejeriern. Riksforen, 86.

160. Bergman, T., Magnusson, A., Berglof, A., and Joost, K. 1966. Influence of a standstill on the quantity and composition of dairy waste water. 17th Int. Dairy Congr., E/F 753-756.

161. Berridge, H. B. 1969. Rural trade wastes. Instn. publ. Hlth. Engrs. J., 68:85-93.

162. Beuthe, C. G. 1962. The determination of oxygen demand of waste waters by the dichromate method. Gesundheits-Ingenieur, 83:70-72.

163. Bhaskaran, T. R., Chakraborty, R. N., Das, N., and Sinha, S. N. 1962. Treatment and disposal of sugar factory effluents. Bull. Hyg., Lond., 37:447.

164. Bhatla, M. N., and Gaudy, F. A. 1965. Studies on the plateau in oxygen uptake during exertion of biochemical oxygen demand by pure cultures of bacteria. Biotechnol. Bioengng., 7:387-404.

165. Bick, H. 1964. The succession of organisms in the self-purification of organically polluted water under different environmental conditions. Minister Fur Ernahrung, Landwirtschaft und Forsten des Landes Nordrhein/Westfalen, Dusseldorf.

166. Biernath, D. 1958. New viewpoints on the treatment of land with dairy effluents. Fette Seifen. Dnstrichmitt. 60:(4)317-318.

167. Bjerre, P. 1970. Reduction of effluent through CIP - system design. 18th Int. Dairy Congr., I - E, A. 1.2, 8.

168. Black, H. H., 1955. Industrial waste treatment as varied as industry. Civil Eng. 25: 96:103.

169. Black, H. H., and Fairall, J. M. 1963. Biological treatment of certain organic wastes. Proc. loth Ontario Ind. Waste Conf., 113-123.

170. Black, H. H., and Klassen, C. W. 1941. Industry abates stream pollution. Sewage Wks. Eng. and Munic. Sanit., 12: 74, 170, and 215.

171. Blank, John. 1969. An analyzer for waste water. Dairy Engng. Conf., 17th Annual Meeting, 67-68.

172. Bloodgood, D. E. 1938. Biological oxidation. Sewage Wks. J., 10: 927-935.

173. Bloodgood, D. E. 1945. Industrial wastes interfere with treatment processes. Sewage Wks. Engng., 16:503.

174. Bloodgood, D. E. 1948. Milk waste disposal. Sewage Wks. J., 20:695-708.

175. Bloodgood, D. E. 1967. Sewage treatment practices. Scranton Gillette, Lancaster, Pennsylvania.

176. Bloodgood, D. E., and Canham, R. A. 1947. How can plant losses by determined? Proc. 3rd Ind. Waste Conf., Purdue Univ., 293-309.

177. Board of County Commissioners of Hamilton County, Ohio. 1968. Rules and Regulations of Greater Cincinnati, Hamilton,County, Ohio, 1-44.

178. Board of Trustees of the metropoliton St. Louis Ordinance No. 1348, 1-19.

179. Bolicek, J. 1950. Problem of water supply in the dairies. Mlek. Letac., 42:(19/20)144-153.

180. Bolton, P. 1952. Industrial waste treatment in Iowa. Proc. Amer. Soc. Civ. Engrs., 78:(149)1-16.

181. Boon, A. G. 1969. The role of contact stabilization in the treatment of industrial waste water and sewage; a progress report. Water Pollut. Control, Lond., 68:67-84.

182. Boon, A.C. 1969. The role of contact stabilization in the treatment of industrial waste water and sewage: A progress report. J. Wat. Poll. Cont. Fed., 41:67-81.

183. Borlaha, L. M., and Idiceano, A. 1950. The presence of nitrites in in milk and its significance. The determination of coliform count by reduction of nitrates. Lait, 29:449-460.

184. Borstlap, C., and Kortland, C. 1968. The biological degradability of non-ionic detergents under aerobic conditions. Biol. Abstr., 49:7,664.

185. Botha, G. R. 1954. The treatment of effluents from milk processing factories. S. Afr. Dairym., 16:(5).

186. Botha, G. R. 1954. Effluent disposal of South African milk processing factories. S. Afr. Dairym. 16:(5).

187. Botha, G. R. 1954. An investigation of the treatment and disposal of effluents from milk processing factories. S. Afr. Council Scientific Industrial Research.

188. Bouthilet, R. J. 1966. Method of removing organic material from waste waters. United States Patent 3,244,621.

189. Bowdler, R. G. 1958. A new field test for farm water supplies. Paper given before the laboratory section of the 1958 annual convention of the Milk Industry Foundation.

190. Brazis, A. R. 1954. Microbological fermentation of dairy wastes. Ph.D. thesis, Univ. of Missouri, Columbua, Mo.; Doctoral Dissertation Series, Publ. No. 9172, University Microfilms, Ann Arbor, Michigan. Chem. Abs., 49:(4196).

191. Breska, G. J., Erickson, P. R., Rohlich, G. A., Anglebert, L. E., and Porges, N. 1957. Objectives and proceedures for a study of spray irrigation of dairy wastes. Proc. 12th Ind. Waste Conf., Purdue Univ., 636-652.

192. Bridgewater, N. P., and T aylor, A. 1947. Effluent disposal in the food industry, Fd. Mf. 22:127.

193. Bullerman, L. B., and Berry, E. C. 1966. Use of cheese whey for vitamin B_{12} production. App. Microbiol. 14:353-360.

194. Bunesova, S., and Dvorak, M. 1968. Dairy waste waters and their aerobic treatment. Vod. Hospod., 18:466-467.

195. Burchert, O. 1966. Abwasser aus der chemischen oberflachenbehandlung (Waste water from the chemical treatment of surfaces). Verlag fur fur Bauwesen (Publication for Architecture), Berlin, 1-192.

196. Burgaud, J. L. 1969. Waste waters in the dairy industry. Lait, 49:(487)417-433.

197. Busch, A. W., Grady, L., Rao, T. S., and Swilley, E. L. 1961. B. O. D. progression in soluble substrates. IV. A short-term total oxygen demand test. Proc. 16th Industr. Waste Conf., Purdue Univ., 67-76.

198. Buswell, A. M. 1939. Biological processes for treating waste. Ind. Eng. Chem., 31:1349.

199. Buswell, A. M., and Pagano, J. F. 1952. Reduction and Oxidation compounds in polluted streams. Sewage Ind. Wastes. 24:897-903.

200. Calvert, H. T. 1938. Milk factory effluents. Rep. Dir. Wat. Pollut. Res., Lond., 12-23.

201. Calvert, H. T. 1939. Milk factory effluents. Rep. Dir. Wat. Pollut. Res., Lond., 16-21.

202. Calvert, J. T., and Amcotts, P. M. 1952. Some problems in the disposal of industrial effluents and domestic wastes. Proc. Inst. Civ. Engrs., 1:141-168.

203. Campbell, W. B. 1949. The dairy industry committee exhibit on waste saving. Proc. 5th Ind. Waste Conf., Purdue Univ., 407.

204. Camus, A., Valat, M., and Claveau, J. 1953. The treatment of dairy wastes with aerobic micro-organisms. 13th Int. Dairy Congr., 3:983-985.

205. Camus, A., Valat, M., and Claveau, J. 1956. Treatment of dairy waste waters with aerobic micro-organisms. Chem. Zbl., 127-5151.

206. Canham, R. A. 1947. The design of an experimental waste treatment plant at the Purdue creamery. Thesis on file, Purdue Univ. Library.

207. Canham. R. A. 1959. Industrial waste disposal by spray irrigation. Sthwest. Wat. Wks. J., 41:(9)14-16, 18-22.

208. Cantinieaux, F. 1954. Some considerations on waste waters from daires and their purification. Bull. mens. Cent. belge Erude Docum. Eaux, No. 24, 103-109.

209. Capestany, G. J., and Carlson, D. A. 1966. Utilization of resistent proteins by activated sludge. Proc. 21st Ind. Waste Conf., Purdue Univ., 943-952.

210. Carl, C. E. 1961. Waste treatment by stabilization ponds. Publ. Hlth. Engng. Abstr., 41:(10)35.

211. Carman, P. C. 1933. A study of the mechanism of filtration. Part I. J. Soc. Chem. Ind. (Brit.), 52:280T.

212. Carr, R. L. 1939. Industrial waste and municipal sewage plants. Proceedings of the 24th annual meeting of the New Jersey sewage works association.

213. Carrick, C. W. 1951. Use of industrial wastes in poultry feedings. Proc. 6th Ind. Waste Conf., Purdue Univ., 130-134.

214. Casalis, J. 1949. Purification of waste waters from the dairy industry, 12th Int. Dairy Congr., 3:Sect. 3, 643-647.

215. Casays, L., and Surum, J. 1968. Disposal by spraying of effluent from agricultural industries. Techn. Lait, 20:(239)19, 21, 23, 25, 27, 29, 31.

216. Cerny, A. 1952. Basic problems of treatment of industrial waste waters. Ost. Wasserw., 4:125-130.

217. Cerny, A. 1957. Special technical problems of industrial waste waters. Wass. u. Abwass., 2:137-149.

218. Cerny, A. 1959. The waste water problem in small and medium-sized milk products factories. Wass. u. Abwass., 4:230-250.

219. Cessna, J. O. 1964. Modesto's pollution explosion. Wat. Wks. Wastes Engng., 1:(2)50-52.

220. Chakrabarty, R. N. 1964. Cane sugar wastes and their disposal. Envir. Hlth. India, 6:265-273.

221. Chakrabarty, R. N., Sen, B. P., Trivedi, R. C., and Blaskaran, T. R. 1963. Treatment of cane sugar wastes in stabilization ponds. Proceedings of symposium on waste treatment by oxidation ponds, October 29-30, Jagpur, India.

222. Chandan, R. C., Gordon, J. F., and Wlaker, D. A. 1969. Dairy fermentation process. Process Biochem., 4:(2).

223. Chang, P. S. 1965. Effect of pollution on oysters and fish in Taiwan. USDA-HEW, Pub. Hlth. Serv. Publ. No. 999-WP-25, 1-434.

224. Chaplin, C. E., and Johns, C. K. 1949. The influence of alkalinity on the germicidal action of hypochlorites. J. Dairy Res., 16:322-326.

225. Charmandarian, M. O., and Ondronikova, N. V. 1950. The basic colloid chemistry of the treatment of dairies waste waters. Techq. Eaux. Bruxelles, 4:(46)10 and 20.

226. Chian, S. K., and Mateles, R. I. 1968. Growth of mixed cultures on on mixed substrates. I. Continuous culture. Appl. Microb. 16: 1337-1342.

227. Chipperfield, P. N. J., Askew, M. W., and Benton, J. H. 1970. Multistage plastic media treatment plants. Proc. 25th Ind. Waste Conf., Purdue Univ., 1-32.

228. Christensen, K. 1969. The experimental dairy waste water treatment plant (1st Annual report). Danish Government Experiment Station, Hillerod, 56-62.

229. Christensen, K. 1970. Oxygen uptake of factory effluents. 18th Int. Dairy Congr., I-E, A. 1.2, 14.

230. Christiansen, M. J., and Jepsen, A. 1945. The occurrence of tubercule bacilli in drain water of slaughter houses, dairies, and rendering plants. Maanedsskv. Dyrloeg., 57:(6)173-193.

231. Christophersen, J. 1940. The development of biological processes for the disposal of dairy wastes. J. Molkereizeitung, Hild., 54:245.

232. Chuda, K. 1940. Hygienic studies on municipal sewage purification. III. The biological purification of individual organic substances by the activated sludge process and the changes in the physical properties of the purified sewage. Mitt. med. Alad. Kioto, 28-525.

233. Chudoba, J., Nemec, M., and Nemcova, B. 1968. Residual organic matter in activated sludge process effluents. II. Degraduation of saccharides and fatty acids under continuous conditions. Sb. vys. Sk. chem.-technol. Praze. Technol. Vod., 13:27-44.

234. Chudoba, J., Prasil, M., and Emmerova, H. 1968. Residual organic matter in activated sludge process effluents. III. Degradation of amino acids and phenols under continuous conditions. Sb. vys. Sk. chem.-technol. Praze. Technol. Vod., 13:45-63.

235. Chynoweth, D. P., Meck, L., and Mah, R. A. 1969. The effect of glucose on the anaerobic sludge fermentation. ESE Notes, 6:(1) 1-2.

236. Cillie, G. G., Henzen, M. R., Stander, G. J., and Baillie, R. D. 1969. Anaerobic digestion. IV. The application of the process in waste purification. Wat. Res., 3:623-643.

237. Clark, R. N. 1962. Water supply and waste disposal for milk processing plants, milk hygiene. WHO, Geneva, Switzerland.

238. Cleeg, L. F. L., and Branka, B. 1968. A comparison of different methods of chemical disinfection of farm dairy utensils. J. Soc. Dairy Technol., 21:(2)72.

239. Clews, J. 1962. Wastes from milk processing. Comp. Sci., 2:(24)42.

240. Clinton, M. O. 1955. Seymour solves unusually difficult waste treatment problem. Wat. Sewage Wks., 102:438-441.

241. Cludius, G. 1955. Treatment of domestic and dairy waste waters in a fish-pond plant. Wass. u. Boden, 7:8-9.

242. Coakley, P., and Jones, B. R. S. 1956. Vacuum sludge filtration. I. Interpretation of results by the concept of specific resistance. Sewage Ind. Wastes, 28:(8)963.

243. Coin, L., and Mathis, M. 1952. Relation between index of putrescibility and oxidation-reduction potential. Bull. mens. Cent. belge Eaux, No. 16, 144-149.

244. Cojocaru, R. 1964. Fat separators in the inner sewage of food industry units. Chem. Abstr., 61:10, 436.

245. Colenso, R. 1967. Synthetic detergents and sewage purification. Publ. Hlth. Inspector, 76:14-16.

246. Colson, R. 1966. Biodegradable detergents. Techq. Eau Assain., No. 237:31-33.

247. Conner, W. R., and Perry, M. J. 1968. Treats liquid wastes more efficiently. Fd. Eng., 48:(2)92-98.

248. Conway, R. A., and Kumke, G. W. 1966. Field techniques for evaluating aerators. Journal SED, ASCE, 92:SA2, 21-42.

249. Cook, D. J., and Wookbine, M. J. 1958. The reduction of the biochemical oxygen demand of whey by controlled mold growth. J. appl. Bact., 21:(2)vii.

250. Cooper, T. B. 1954. Spray irrigation in the disposal of industrial wastes. Milk wastes. Proc. 1st Ontario Ind. Waste Conf., 47-49.

251. Costopoulos, J. M. 1959. An experimental study on the rate of oxidation of organic wastes in soil. Diss. Abstr., 20:2194.

252. Cousin, B. 1939. The utilization of dairy effluent in agriculture. J. Molkereizeitung, Hild., 53:1728.

253. Coutris, R. 1952. Some considerations on the treatment of waste waters from dairies. Tech. de l'Eau, 6:(66)23-29.

254. Cowie, C. A. 1960. Industrial waste treatment and disposal in New Zealand. Proc. 15th Ind. Waste Conf., Purdue Univ., 9-14.

255. Cox, G. A., and Whitehead, H. R. 1949. Chemical sterilization of dairy equipment. The bactericidal action of chlorine in the presence of protein. J. Dairy Res., 16:327-333.

256. Creswell, P., Ellerker, R. and Evers, D. 1965. Some aspects of northern industrial effluents. J. Proc. Inst. Sew. Purif., 360-366.

257. Croakett, V. P. 1942. Treatment methods for creamery and dairy wastes. Publ. Hlth. Eng. Abstr., 21:(6)S:75.

258. Culpin, C. 1964. Equipment for disposal of agricultural effluents. Chemy. Ind., 44:350.

259. Cuthbert, W. A. 1955. Bacteriological aspects of dairy water supplies. J. Soc. Dairy Technol., 8:181-184.

260. Cyr, R. 1958. Treatment of waste waters from food industries. Chem. Abl., 129 1111.

261. Dairy Effluents Sub-Committee on the Milk and Milk Products Technical Advisory Committee. 1969. Dairy effluents. Department of Agriculture and Fisheries for Scotland.

262. Dairy Industry Committee, Sub-Committee on Dairy Waste Disposal. 1952. An industrial waste guide to the milk processing industry. Publ. Hlth. Eng. Abstr., 32:(9)22-23.

263. Dairy Industry Committee, Subcommittee on Dairy Waste. 1956. Dairy waste prevention and treatment. Sth. Dairy Prod. J., 60:(4) 216-238.

264. Dairy Industry Committee, Subcommittee on Dairy Waste. 1956. Seek economical waste treatment. Milk Plt. Mon., 45:13-14, 32.

265. Dairy Industry Committee, Subcommittee on Dairy Waste. 1957. Dairy waste subcommittee meets in up-state New York. Milk Prod. J., 48:(6)82.

266. Dairy Sanitation Engineers Committee. 1950. Dairy waste saving and treatment guide for milk plant operators. Pennsylvania Assn. of Milk Dealers, Inc.

267. Dalrymple, W., and Proctos, D. E. 1967. Feasibility of dairy manure stabilization by anaerobic digestion. Wat. Sewage Wks., 114:361-364.

268. Danish Experiment Station (Hillerod). 1954. Some factors in the installation and operation of spraying equipment for dairy wastes. Maelkeritidende, 67:(29)708.

269. Davis, J. A. 1947. Disposal of dairy factory wastes. Aust. J. Dairy Technol., 2:(3)91-100.

270. Davis, J. G. 1950. A dictionary of dairying. Leonard Hill Ltd., London, 1.876.

271. Davis, J. G. 1959. The microbiological control of water in daries and food factories. Wat. and Wat. Eng., 63:411-413.

272. Davy, P. S. 1952. Pre-treatment of milk wastes reduces treatment plant load. Publ. Wks., Lond., 83:(1)56.

273. Davy, P. S., and Noth, M. J. 1947. Milk losses and milk waste disposal. Publ. Wks., N. Y., 78:(7)22-23 and 66-67.

274. Dean, W. A., Jr. 1946. Dairy waste saving and disposal. Ass. Bull. (Milk Ind. Found.) Ass. Bull. (Int. Ass. Milk Dlrs.), 39:(2)31-42.

275. Dean, W. A., Jr. 1947. The Dairy Industry Committee's Task Committee on waste disposal-its objectives and organization. Proc. 3rd Ind. Waste Conf., Purdue Univ., 282-287.

276. Dean, W. A., Jr. 1948. Report of task committee, problem of dairy waste disposal. Milk Industry Foundation, 7-12.

277. Dean, W. A., Jr. 1950. What is new in dairy waste saving and disposal? Proc. 43rd Ann. Conv., Milk Ind. Found., Plant Sec., 2:18.

278. DeMartini, F. E., Moore, W. A., Terhoeven, G. E. 1946. Food dehydration wastes. A study of wastes from the dehydration of skim milk, raw and fermented whey, potatoes, beets, rutabagas, and hominy. Publ. Hlth. Rep., Wash., Suppl. No. 191, 1-40.

279. Demmler, G. 1950. Yeast production in whey according to the Waldhof process. Chem. Abstr., 44:4195-4196.

280. Dendy, P. 1961. Rural wastes. Publ. Hlth. Eng. Abstr., 41:(11) 34.

281. Denecke, K. 1957. Influence of sewage-irrigation on the viability of tubercle bacilli and pathogenic intestinal bacteria. Arch. Hyg., Berl., 141:(7)557-562.

282. Dennis, J. M. 1953. Spray irrigation of food processing wastes. Sewage ind. Wastes, 25:(5)591-595.

283. Department of Scientific and Industrial Research. 1939. Report of the Water Pollution Research Board for the year ended 30th June, 1939, with report of the Director of Water Pollution Research. H. M. Stationery Office, Lond., 1-54.

284. Department of Scientific and Industrial Research. 1941. Salvage in the milk industry. Summary. Water Pollution Research Technical Paper No. 8, London.

285. Department of Scientific and Industrial Research. 1942. The treatment and disposal of waste waters from dairies and milk products factories. Water Pollution Research Technical Paper No. 8, Lond.

286. Department of Scientific and Industrial Research. 1947. Report of the Water Pollution Research Board with the report of the Director of Water Pollution Research 1st July, 1939, to Dec. 31, 1945. H. M. Stationery Office, Lond., 1-82.

287. Derenk, G., Schmid, C. O., and Sontheimer, H. 1969. Apparatus and process for biological purification of waste water containing foam-forming substances. United States Patent 3,224,964.

288. Deutsche. Kommission Zur Vereineitlichung der Untersuchungsmethoden Fur Milch, Milch produket, und Molkereihilfstoffe. 1960, Michobiological methods for the examination of water for milk products factories. Milchwissenschatf, 15:340-345.

289. Dewes, E. 1960. Experiences and results with a new anaerobic biological process for treatment of certain polluted industrial waste waters. Ber. AbwassTechn. Verein., (12)169-177.

290. Deyl, Z. 1961. Anaerobic fermentations. Sci. Pap. Inst. chem. Technol., Prague, Technol. Wat., 5:Pt. 2, 131-234.

291. Dias, F. F. and Bhat, J. V. 1964. Microbial ecology of activated sludge. I. Dominant bacteria. II. Bacteriophages, Bdellovibrio, coliforms, and other organisms. Appl. Microbiol., 12:412.

292. Dickinson, D. 1960. Industrial effluents. J. Fd. Mfr. Fed. Inc., 47:142-145.

293. Dickinson, D. 1963. Purification of effluents from food manufacture. Effl. Wat. Treat. J., 3:373-376.

294. Dickinson, D. 1967. Effluents from the industrial preparation of food. J. Proc. Inst. Sew. Purif., 66:159-164.

295. Dickinson, J. 1956. New tool for solving waste disposal problems. Publ. Hlth. Eng. Abstr., 36:(3)29.

296. Diepman, A. J. 1955. The dairy industry products too much waste water. Zuivelfabrick, 2:(1)9, (2)9, (3)12, (4)13, (6)13, (7)10, (8), (9), (10).

297. Dieterich, K. R. 1960. Waste utilization and waste water treatment in the biochemical industries. Alfred Huthing, Heidelburg.

298. Dieterich, K. R. 1961. Waste water problems in the dairy industry. Molkereizeitung, 15:263.

299. Dietz, J. C 1968. Joint treatment of municipal and industrial wastes. 16th Dairy Eng. Conf., Michigan State Univ., 1-17.

300. Dirking, H., and Sudholt, H. 1956. Thoughts and practical suggestion suggestions regarding the dairy waste problem. Molk -u. Kas,-Ztg., 7:1115.

301. Divet. 1957. Modern percolating filters. Bio-filtration. Tech. Sanit. Munic., 52:210-126.

302. Dolby, R. M. 1970. Disposal of dairy factory effluent in New Zealand. 18th Int. Dairy Congr., I - E, A. 1.2, 10.

303. Donlan, R. 1958. Rapid method for estimating BOD values of wastes. Sanitalk, 6:(3)22.

304. Dowgiallo, A. 1965. The occurrence and breakdown of carbohydrates in astatic waters. Verh. int. Berein. theor. angew Limnol., 16:532-538.

305. Drake, R. J., Hepburn, E. A., and Trembath, R. H. N. 1940. Dairy factory effluents. J. Dept. Agric. Vict., 38:28-29, 31.

306. Drier, D. E. 1954. Air diffusion for activated sludge. Proc. 9th Ind. Waste Conf., Purdue Univ., 56-60.

307. Dugan, F. C. 1947. The industrial waste problem in Kentucky. Proc. 3rd Ind. Waste Conf., Purdue Univ., 354-359.

308. Dyer, A. E. 1953. Sewage disposal works for the borough of Great Torrington. J. Inst. Sew. Purif., Pt. 3, 198-200.

309. Eck, A. 1969. Disposal of dairy effluent. Lait, 49(485/486)235-245.

310. Eckenfelder, W. W., Jr. 1952. Aeration efficiency and design. I. Measurement of oxygen transfer efficiency. II. Design from pilot plant data. Sewage ind. Wastes, 24:1221-1228, 1361-1367.

311. Eckenfelder, W. W., Jr. 1956. Studies on the oxidation kinetics of biological sludges. Sewage ind. Wastes, 28(8)983.

312. Eckenfelder, W. W., Jr. ed. 1964. Proceedings of the 1st international conference on water pollution, advances in water pollution research. 3 Volumes. Pergamon, New York.

313. Eckenfelder, W. W., Jr. 1967. Proceedings of the 2nd international conference on water pollution, advances in water pollution research 3 Volumes. Pergamon, New York.

314. Eckenfelder, W. W., Jr. 1970. Manual of treatment process, Co Volume I. Environmental Science Services Corporation.

315. Eckenfelder, W. W., and O'Connor, D. J. 1961. Biological waste treatment. Pergamon Press, New York.

316. Edeline, F., Beneden, G. V., Lambert, G., and Fatticcioni, H. 1967. Study of a purification plant for dairy waste waters at Ambleve. Trib. CEBEDEAU, 20:344-356.

317. Eden, G. E., Truesdale, G. A., and Mann, H. T. 1966. Biological filtration using a plastic filter medium. J. Proc. Inst. Sew. Purif., 562-574.

318. Edmondson, J. E., and Brazis, A. R. 1955. Microbiolgical fermentation of dairy wastes. J. Dairy Sci., 38:(6)597.

319. Edwards, G. P. 1938. Research in sewage chemistry, sewage treatment and stream pollution. Sewage Wks. J., 10:(2)173-208.

320. Edwards, G. P., Kesavulu, V., Smith, S., and Lulla, K. B. 1961. Frothing of detergents in the presence of carbodydrates, fats, and proteins, J. Wat. Poll. Cont. Fed., 33:737-747.

321. Eichel, H. 1963. The use of milk centrifugal sludge in poultry feeding. Arch. fuer Tierernaehr, 13:107.

322. Eideness, F., and Kalinski, A. 1959. Anaerobic digester for industrial wastes such as packing house or dairy effluents. United States Patent 2,907,712.

323. El-Baroudi, H. M., and Moawad, S. K. 1967. Rate of BOD reduction by oxidation ponds. J. Wat. Poll. Cont. Fed., 39:1626.

324. Elder, A. L., and Stahl, G. W. 1939. Ferric oxide hydrosols as coagulants in waste treatment. Ind. Eng. Chem., 31:925-926.

325. Eldridge, E. F. 1930. The treatment of milk products waste. Report 2. Mich. Eng. Exp. Sta., Bull. 28, 1-31.

326. Eldridge, E. F. 1936. The disposal of wastes from milk products plants. Mich. Eng. Exp. Sta., Bull. 272.

327. Eldridge, E. F. 1938. Industrial waste treatment processes and plant design. Mich. Eng. Exp. Sta., Bull. 83, 1-103.

328. Eldridge, E. F. 1938. Cheese factory waste treatment by the Guggenheim process. Mich. Eng. Exp. Sta., Bull. 83, 9-04.

329. Eldridge, E. F. 1939. Effect of industrial waste on municipal sewage treatment. Munic. Sanit., 10:419.

330. Eldridge, E. F. 1939. A full scale high-rate recirculating filter for milk waste. Mich. Eng. Exp. Sta., Bull. 87, 11-14.

331. Eldridge, E. F. 1941. Milk waste treatment by the Mallory process. Waterworks and Sewerage, 88:(10)457-462.

332. Eldridge, E. F. 1941. The recirculating high-rate filter in industrial waste treatment. Waterworks and Sewerage, 88:483.

333. Eldridge, E. F. 1941. Recent trade waste disposal methods. Sewage Wks. J., 13:105.

334. Eldridge, E. F. 1942. Some comments on the Mallory process (A discussion). Waterworks and Sewerage, 89:(4)155.

335. Eldridge, E. F. 1942. Industrial waste treatment practice. McGraw-Hill Book Company, Inc., New York.

336. Eldridge, E. F. 1942. The oxidized sludge and regenerative treatment plant at Zeeland, Michigan. Sewage Wks. J., 14:748-752.

337. Eldridge, E. F. 1947. Research needed in milk waste disposal. Proc. 3rd Ind. Waste Conf., Purdue Univ., 316-320.

338. Eldridge, E. F. 1949. Waste prevention in the dairy industry. Proc. Conf. Ind. Wastes, Eng. Exp. Sta. Washington Univ., 57-59.

339. Eldridge, E. F. 1949. Dairy waste disposal. Sewage Wks. J., 21:(4)668-673.

340. Eldridge, E. F. 1951. 15 ways to reduce waste from milk plants. Wastes Eng., 22:270.

341. El-Erian, A. F. M. 1969. Bacteriological Studies on Limburger Cheese. H. Veenman and Zonen N. V.-Wageningen, Netherlands.

342. Elsdon, G. D., and Gibson, M. 1941. Reports of the progress of applied chemistry. Volume XXVI. Society of Chemical Industry, London.

343. El-Sharkawi, F. M. and Moawad, S. K. 1970. Stabilization of dairy wastes bu algal-bacterial symbiosis in oxidation ponds. J. Wat. Poll. Cont. Fed., 43:115-125.

344. Emmons, D. B. 1963. Recent developments in the manufacture of cottage cheese. Part I and Part II. Dairy Sci. Abstr., 25:(4) 129-137.

345. Enebo, L., Lundin, H., and Myrback, K. 1941. Yeast from whey. Svenska Kem. Tidskr., 53:96.

346. Erb, J. H. 1968. Good housekeeping-who is responsible for this task? Can. Dairy and Ice Cream J., 47:(8)24.

347. Etablissements, S. 1941. Purification of waste waters from daries and cheese factories. Chem. Zbl., 139:(2)3862.

348. Ettelt, G. A., and Kennedy, J. J. 1966. Research and operational experience in sludge dewatering at Chicago. J. Wat. Poll. Cont. Fed., 38:(2)248.

349. Ewbank, F. W. 1967. Dairy plant waste disposal by ridge and furrow irrigation. 15th Ann. Dairy Eng. Conf., Michigan State University.

350. Fair, G. M., Geyer, J. C., and Okun, D. A. 1966. Water and waste water engineering, Vol. 1: Water supply and waste water removal. John Wiley, New York, 1-489.

351. Fair, G. M., Geyer, J. C., and Okun, D. A. 1968. Water and waste-water engineering. Volume 2. Water purification and waste-water treatment and disposal. John Wiley and Sons, Inc., New York, 1-670.

352. Fairall, J. M. 1952. Statistical analysis of trickling filter data. Sewage ind. Wastes, 24:1358-1360.

353. Faivre, R. 1955. The treatment of water supplies for dairies by means of condensed phosphates. Tech. de l'Eau, 9:(107)29-33.

354. Farrington, E. H., and Davis, G. J., Jr. 1915. The disposal of creamery sewage. Agr. Exp. Sta., Univ. of Wis., Bull. 245.

355. Federal Water Pollution Control Administration. 1967. The cost of clean water. Vol. III-Industrial Waste Profile No. 9-Dairies. Fed. Wat. Poll. Cont. Admin., Publ. No. I. W. P.-9, U. S. Gov. Printing Office, Washington, D.C.

356. Federal Water Pollution Control Administration. 1970. Projects of the Industrial Pollution Control Branch. Water Pollution Control Research Series DAST-38, 1-167.

357. Fenelon, E. S. 1943. How to meet the demand for better waste disposal. Fd. Ind., 15:(7)84.

358. Fife, C. L., and Nilson, K. M. 1969. Production, disposal and use of whey in Vermont. Agr. Ecper. Sta., Univ. of Vermont, Bull. 658.

359. Finch, J. 1953. What the other fellow thinks describes conference of the British Sewage Institute. Wat. Sewage Wks., 100:506.

360. Finn, R. K. 1954. Agitation-aeration in the laboratory and in industry. Bact. Rev. 18:254-274.

361. Fischerstrom, C. N. H., Isgard, E., and Larsen, I. 1967. Settling of activated sludge in horizontal tanks. J. sanit. Engng. Div. Am. Soc. Civ. Engrs., 93:(SA3)73-83, Paper No. 5302.

362. Fish, H. 1964. Pollution prevention in relation to agricultural effluent. Chemy. Ind., 44:354.

363. Fisher, W. J. 1968. Treatment and disposal of dairy waste waters: A review. Dairy Sci. Abstr., 30:(11)567-577.

364. Fleer, J. M., and Baltjes, J. 1957. Smaller milk losses by afterspraying of milk cans. Off. Org. Koninkl. ned. Zuivelb. F. N. Z., 49:613-616.

365. Flinspach, H. 1958. Waste water purification in dairies by irrigation. Molkereizeitung, 12:912.

366. Florida State Board of Health, Bureau of Sanitary Engineering. 1953. Experimental pilot plant studies treatment wastes-Laundry, milk, and restaurant wastes treatment included. Wastes Eng., 24:512.

367. Flynn, K. 1960. A modern irrigation system for disposing of dairy effluent. Dairymfg. Dig., 7:(2)34-38.

368. Fogarty, F. D. 1942. Treating waste fatty effluents. Chem. Abstr., 36:2,068.

369. Food and Agricultural Organization of the United Nations. 1964. Groundwater legislation in Europe. F. A. O. Legislative Ser. No. 5, Rome, Italy.

370. Fox, W. K. 1954. Progress in dairy waste disposal. Summarized from notes taken at the 49th annual meeting of the American Dairy Science Convention.

371. Fraser, J. S. 1968. Dairy factory effluent treatment by a trickling filter. Aust. J. Dairy Technol., 23:(2)104-106.

372. Freitas, H. B. D. 1955. Dairy by-products, losses in the dairy industry. Coop. Cent. des Prod. de Leite, 8:(7)30.

373. Fritsch, W. 1957. Progress report on experiments on the treatment of dairy waste waters by the activated sludge process. Wass. U. Boden, 9:170-171.

374. Fritz, A. 1960. Determination of water pollution by dairy effluent. Milchwissenschaft, 15:(12)609-612.

375. Frobrich, G. 1960. Operation report on the biological treatment plant at the cheese factory of the firm of Kraft in Schwabmunchen. Ber. AbwassTechn. Verein., (11)247-253.

376. Froedge, R. 1967. Activated sludge system of waste disposal. 15th Ann. Dairy Eng. Conf., Michigan State University.

377. Fromageries Belge Society. 1955. A process and installation for the treatment of fermentescible industrial residuary waters and particularly residuary waters from milk industries. British Patent 743-512.

378. Fromageries Belge Society. 1957. Treatment of fermentable, especially milk trade, waste waters. Chem. Zbl., 128:11, 748.

379. Funke, J. W. 1967. The industrial and effluent management in the milk processing industry. Dairy Ind. J. sth Afr., 7:(2)51, 53, 55, and 57-61.

380. Funke, J. W. 1969. A guide to water conservation and water reclamation in industry. National Institute for Water Research, Council for Scientific and Industrial Research, Pretoria, South Africa, 1-99.

381. Furhoff, W. 1961. Experiments on the biological treatment of milk trade waste waters. Von Wasser, 28:105-111.

382. Furhoff, W. 1961. Experiments on the biological treatment of dairy wastes. Vom Wasser, 28:430.

383. Gardiner, D. K., and Montgomery, H. A. C. 1968. The treatment of sewage effluents with ozone. Wat. Waste Treat., 12:92-96 and 98-102.

384. Gatellier, C., and Appert, J. 1966. Detergents and biodegradability. J. appl. Chem. Abstr., 16:(ii)216.

385. Gauchman, S. S. 1940. Properties of waste waters from butter factories andprocesses for their purification. Vodos. sanit. Tekh., 15:(1)50.

386. Gaudy, A. F. 1962. Colorimetric determination of protein and carbohydrate. Ind. Wat. Wastes, 7:17-22.

387. Gaudy, A. F., Bhatla, M. N., and Gaudy, E. T. 1964. Use of chemical oxygen demand values of bacterial cells in waste-water purification. Appl. Microbiol., 12:(3)254-260.

388. Gault, G. 1960. BOD shock load. J. Wat. Poll. Cont. Fed., 32:903.

389. Gaumnitz, E. W. 1949. Methods of instigating research in dairy waste under the Research and Marketing Act. Proc. 5th Ind. Waste Conf., Purdue Univ., 421.

390. Gellman, I., and Heukelekian, H. 1951. Studies of biochemical oxidation by direct methods. I. Direct method for determining BOD. Sewage ind. Wastes, 23:1267.

391. Gellman, I., and Heukelekian, H. 1955. Studies on biochemical oxidation by direct methods. V. Effect of various seed materials on the rates of oxidation of industrial wastes and organic compounds. Sewage ind. Wastes, 27:793-801.

392. Gellman, I., and Heukelekian, H. 1956. Studies of biochemical oxidation by direct methods. III. Oxidation and purification of industrial wastes by activated sludge. Sewage ind. Wks. J., 28:(8)983.

393. Genin, G. 1953. Better utilization of milk by-products facilitates the problem of waste and wash-water disposal in the dairy. Lait, 33:458-464.

394. Gillar, J. 1966. Water management at the International Dairy Congress. Vod. Hospod., 16:426.

395. Gillar, J. 1969. Succession of micro-organisms during purification of dairy waste waters in stabilization tanks. Microbiol. Abstr., 4:4,786.

396. Gillar, J. 1970. Biocenosis in dairy wastes purification plants. 18th Int. Dairy Congr., I - E, A. 1.2, 15.

397. Gillar, J., and Marvan, P. 1964. Biological investigations on the single-stage fermentation process. Sb. vys. Sk. chem.-technol. Praze, Technol. Vod., 8:Pt. 2, 221-249.

398. Gillar, J., and Marvan, P. 1966. First biological studies of a single-stage fermentation method for the purification of dairy effluent. Prum. Potravin, 17:(6)328-335.

399. Gillar, J., and Stelcova, D. 1963. Estimation of coliform bacteria in dairy wastes. Sb. Praci vysk. Ust. mlek., 118-129.

400. Gils, H. W. van. 1960. Bacteriology of activated sludge. Research Institute for Public Health Engineering, T. N. O. Delft, The Netherlands, Report No. 32.

401. Glendinning, P. B. 1939. Inaugural address to the Edinburgh and district association of the Institute of Civil Engineers. J. Institution civil Engrs., (2)14.

402. Gloyna, E. F. 1950. Milk waste treatment on an experimental trickling filter. Wat. Sewage Wks. J., 97:(11)473-478.

403. Glushehenko, F. F., and Chedurda, A. F. 1943. The most efficient schemes and methods for the purification of waste waters. Chem. Abstr., 37:5, 532.

404. Gockel, I. H. 1961. I. Waste water and sludge clarification. Vom Wasser, 28:94.

405. Gottschald, N., and Koppe, W. 1965. Space loading and sludge activity in laboratory experiments on the biodegradability of detergents. Fortschr. Wasserchem. Grenzgeb., No. 3, 217-222.

406. Gotz, A. 1960. The treatment of milk trade waste waters in an oxidation channel. Ber. Abwasstechn. Verein., No. 11. 254-263.

407. Graaf, A. 1960. Irrigation of grassland with dairy waste waters. Veet.-en. Zuivelbericht, 2:(11)343-349.

408. Graaf, A., and Baltjes, J. 1960. Waste volume, population equivalent and sewer load. Off. Org. Koninkl. Ned. Zuivelb, F. N. Z., 52:44.

409. Green, F. G. 1957. Cannery wastes disposal. A selected annotated bibliography. Nat. Res. Coun. Ottawa, T. I. S. Rep. No. 50, 1-36.

410. Green, S. R. 1964. Principles and applications in aquatic microbiology. John Wiley and Sons, Inc., 430-440.

411. Greenway, J. 1957. Methods to reduce sewage and water costs in dairy plants. Proc. 8th Pacific Northwest Ind. Waste Conf., Washington State Coll., 41.

412. Greiner, F. J. 1968. Dairy industry and environmental waste. J. Dairy Sci., 51:1151.

413. Grewis, O. E., and Burkett, C. A. 1966. Two-thousand town treats twenty-thousand waste. Wat. Wastes Eng., 3:(6)54-57.

414. Griffith, L. B. 1957. Milk waste treatment. United States Patent 2,792,202.

415. Gromski, L. 1965. Technical and economic aspects of using activated sludge in purification of small amounts of sewage. Chem. Abstr., 63:1,286.

416. Gronau, J., and Koster, H. 1967. Effect of detergents on pH of dairy effluent. J. Molkereizeitung, Hild., 21:(48)1477-1480.

417. Gronau, J., and Koster, H. 1968. Study of effluent in modern-milk processing plants. Molkereitechnik., 15:59-69.

418. Groves, F. W., and Graff, T. F. 1965. An economic analysis of whey utilization and disposal in Wisconsin. Univ. of Wis., College of Agr. and Agr. Econ., Bull. 44.

419. Gupta, S. D. 1966. Problem of industrial waste treatment with particular reference to the treatment of wastes from sugar factories. Sug. Ind. Abstr., 28:174.

420. Gurnham, C. F. 1956. Latest developments in the treatment of dairy wastes. Ind. Wastes, 1:227-229.

421. Gurnham, C. F. 1965. Industrial waste-water control. Academic Press, New York & London, Chem. Technol. Ser. Monogr., Vol. 2, 1-486.

422. Gwynedd River Board. 1964. 13th and 14th annual reports for the years ended 31st March, 1963 and 31st March, 1964.

423. Haack, K. 1954. Hygienic aspect of the use of dairy wastes for agricultural purposes. Gesundheitsingenieur, 75:(13/14)226-229.

424. Halasz, A. 1965. On questions of microbiology in waste-water purification in the food industries. Hung. tech. abstr., 17:118.

425. Hanrahen, F. P., and Webb, B. H. 1961. Spray drying cottage cheese whey. J. Dairy Sci., 44:1171.

426. Hansen, P. S., and Krough, O. 1968. Laboratory scale purification of dairy effluent by plastics filters. Nord. Mejeritidsskr., 35:(10)194-197.

427. Hansen, R. L. 1954. Mayfield, Kentucky, sewage treatment plant nearing completion. Wastes Eng., 25:139-147.

428. Harding, H. G. 1962. Symposium on liquid industrial wastes. Dairy industry. Ind. Eng. Chem. 44:(3)487-491.

429. Harding, H. G. 1952. Dairy industry. Ind. Eng. Chem., 44:487-491.

430. Harding, H. G. 1961. Milk waste treatment. Pap. 8th Ontario Ind. Waste Conf., 67-77.

431. Harding, H. G. 1966. Water Quality Act of 1965-Impact on the dairy and food industry. J. Milk Fd. Technol., 29:350.

432. Harding, H. G. 1968. Dairy waste disposal system. Amer. Dairy Rev., 31:32.

433. Harding, L. 1963. Utilization of milk by-products: Whey. J. Soc. Dairy Ind., 16:(2)53.

434. Hare, J. H., and Baker, B. E. 1951. The precipitation of whey proteins using waste sulphite liquor. Can. J. Technol., 29:332-336.

435. Harmon, L. G. 1957. Bacteriological condition of water supplies in dairy plants. Publ. Hlth. Eng. Abstr., 37:(12)31.

436. Harwood, J. H. 1953. The uses and limitations of aluminum sulphate in the chemical coagulation of trade effluents. Contract Rec., 64:22.

437. Hasfurther, W. A. 1951. Aeration gives low cost waste disposal. Fd. Ind., 23:90-93.

438. Hasfurther, W. A., and Klassen, C. W. 1949. Aeration of milk wastes. Proc. 5th Ind. Waste Conf., Purdue Univ., 72, 424-430.

439. Hatch, B. F. and Bass, J. H. 1939. A study of milk waste treatment. 13th annual report, Ohio Conf. on Sewage Treatment, 50-91.

440. Hauer, G. E. 1952. Successful treatment of dairy waste by aeration. Sewage Ind. Wastes, 24:1271-1277.

441. Hauer, G. E. 1954. Air diffusion in the treatment of industrial wastes. Proc. 9th Ind. Waste Conf., Purdue Univ., 60-63.

442. Hegbom, S. S. 1955. Continuous culture of Saccharomyces fragilis. Proc. 2nd Ontario Ind. Waste Conf., 133-144.

443. Heider, R. W. 1946. Stream pollution in the Blue River basin. Sewage Wks. J., 18:170.

444. Heldman, D. R., and Hedrick, T. I. 1968. Dairy engineering progress in America. Dairy Ind., 33:312.

445. Hellstrom, B. 1949. Method for diminishing the content of impurities in dairy waste water by taking care of milk spillage. 12th Int. Dairy Congr., 3:Sect. 3, 648-651.

446. Helmers, E. N., Frame, J. D., Greenberg, A. E., and Sawyer, C. N. 1952. Nutritional requirements in the biological stabilization of industrial wastes. II. Treatment with domestic sewage. III. Treatment with supplementary nutrients. Sewage ind. Wastes, 24:(4)496.

447. Hemens, J. 1963. The treatment of organic trade effluents. Fd. Inds. S. Afr., Dec., 1963, and Jan., 1964.

448. Hepburn, E. A. 1938. The purification and disposal of milk wastes. Hlth. Bull., Melb., 1478-1490.

449. Hess, F., and Meer, F. 1952. The treatment of milk trade waste waters. Wass. u. Boden, 4:(1)4.

450. Heukelekian, H. 1941. Activated sludge bulking. Sewage Wks. J., 13:39.

451. Heukelekian, H., and Gellman, I. 1951. Studies of biochemical ocidation by direct methods. II. Effect of certain environmental factors on the biochemical oxidation of wastes. Sewage and ind. Wastes, 23:(12)1546-1563.

452. Heukelekian, H., and Gellman, I. 1955. Studies of biochemical oxidation by direct methods. IV. Effect of toxic metal ions on oxidation. Sewage ind. Wastes, 27:(1)70-84.

453. Heukelekian, H., and Rand, M. C. 1955. Biochemical oxygen demand of pure organic compounds. Sewage ind. Wastes, 27:1040-1053.

454. Heukelekian, H., Babbitt, H. E., and Bloodgood, D. E. 1944. A critical review of the literature of 1944 on sewage and waste treatment and stream pollution. Sewage Wks. J., 17:223.

455. Heukelekian, H., Orford, H. E., and Manganelli, R. 1951. Factors affecting the quantity of sludge production in the activated sludge process. Sewage ind. Wastes, 23:(8)945.

456. Hicks, S. E., and Carey, F. G. 1968. Glucose determination in natural waters. Limnol. Oceanogr., 13:361-363.

457. Higgins, P. M. 1967. Waste stabilization lagoons-their operating problems and new developments in their design. Wat. Poll. Control, Ontario, Manual and Directory, 23-34.

458. Hinin, E. 1953. Determination of lactose in dairy wastes, Sewage ind. Wastes, 25:(2)188-190.

459. Hinds, H., Jr. 1969. Systems for the reuse of water. 17th Ann. Dairy Engng. Conf., Mich. St. Univ., 55-62.

460. Hlavka, M. 1966. Effect of detergent on the purification of dairy effluent. Prum. Potravin, 17:(11)558-561.

461. Hlavka, M. 1969. Activated sludge purification of effluent from the Madeta dairy factory in Ripec. Prum. Potravin, 20:(11)329-332.

462. Hobbie, J. E., and Wright, R. T. 1965. Bio-assay with bacterial uptake kinetics: Glucose in fresh water. Limnol. Oceanogr., 10:471-474.

463. Holland, R. F. 1966. Pollution raises problems for dairy industry. Am. Dairy Rev., 28:(11)38.

464. Hollowell, R. 1944. History and legal background of stream pollution control in Indiana. Proc. 1st Ind. Waste Conf., Purdue Univ., 1-190.

465. Holt, R. F., Timmons, D. R., and Latterell, J. J. 1970. Accumulation of phosphates in water. J. Agr. Food Chem., 18:(5)781-784.

466. Hoover, S. R. 1953. Biochemical oxidation of dairy wastes. V. A. review. Sewage ind. Wastes, 25:(2)201-206.

467. Hoover. S. R., and Jasewicz, L. B. 1966. Agricultural processing wastes: Magnitude of the problem. Yearbook of Agriculture, 187-203.

468. Hoover, S. R., and Porges, N. 1950. Treatment of dairy wastes by aeration. II. Continuous aeration studies. Proc. 5th Ind. Waste Conf., Purdue Univ., 137.

469. Hoover, S. R., and Porges, N. 1952. Assimilation of dairy wastes by activated sludge. II. The equation of synthesis and rate of oxygen utilization. Sewage ind. Wastes, 24:306-312.

470. Hoover, S. R., Jasewicz, L., and Porges, N. 1951. Vitamin B_{12} in activated sewage sludge. Science, 114:(2956)213.

471. Hoover, S. R., Jasewicz, L., and Porges, N. 1952. Biochemical oxidation of dairy wastes. IV. Endogenous respiration and stability or aerated dairy-waste sludge. Sewage ind. Wastes, 24:1144-1149.

472. Hoover, S. R., Jasewicz, L., and Porges, N. 1952. Endogenous respiration and stability of aerated dairy waste sludge. Proc. 7th Ind. Waste Conf., Purdue Univ., 541-548.

473. Hoover, S. R., Jasewicz, L., and Porges, N. 1954. Biochemical oxidation of dairy wastes. Relationship between the rate of purification and rate of oxidation and graphical estimation of first order velocity constants. Proc. 9th Ind. Waste Conf., Purdue Univ., 71-79.

474. Hoover, S. R., Jasewicz, L., Porges, N. 1956. Aerobic process for treatment of dairy wastes. Proc. 14th Int. Dairy Cong. 2:(2)238-243.

475. Hoover, S. R., Porges, N., and Jasewicz, L. 1953. An interpretation of the BOD test in terms of endogenous respiration of bacteria. Sewage ind. Wastes, 25:(10)1163-1173.

476. Hoover, S. R., Jasewicz, L., Pepinsky, J. B., and Porges, N. 1951. Assimilation of dairy wastes by activated sludge. Sewage ind. Wastes, 23:(2)167-173.

477. Hoover, S. R., Pepinsky, J. B., Jasewicz, L., and Porges, N. 1951. Aeration as a partial treatment for dairy wastes. Proc. 6th Ind. Waste Conf., Purdue Univ., 313-319.

478. Horton, B. S., Eykamp, W., Goldsmith, R. L., and Hossain, S. 1970. Membrane separation processes for the abatement of pollution from whey. 18th Int. Dairy Congr., I - E, A. 4. 10, 442.

479. Horton, J. P., and Trebler, H. A. 1953. Recent development in the design of small milk waste disposal plants. Proc. 8th Ind. Waste Conf., Purdue Univ., 32-45.

480. Horton, J. P., and Trebler, H. A. 1953. Recent developments in design of small milk waste disposal plants. Sewage ind. Wastes, 25:941-949.

481. Horton, J. P., and Trebler, H. A. 1954. Recent developments in design of small milk waste disposal plants. Can. Dairy Ice Cream J., 33:(4)38-41 and 78.

482. Houran, G. A. 1969. Practical uses of whey. 17th Ann. Dairy Engng. Conf., Mich. St. Univ., 69-74.

483. Hubner, K. 1963. Measures for the savings in water in dairy plants. Molk.-u. Kas.-Ztg., 14:365.

484. Hudig, H. 1951. Purification of dairy waste waters by spray irrigation. Deutsche Molkerei Zeits., 5:58.

485. Hugh, R., and Leifson, E. 1967. The taxonomic significance of fermentative versus oxidative metabolism of carbohydrates by various Gram-negative bacteria. J. Bact., 66:24.

486. Husmann, W. 1940. Utilization of sewage and industrial waste waters. Ver. dtsch. Ing., 84:657.

487. Husmann, W. 1941. Modern sewage purification. Chemikereizeitung, 65:452 and 473.

488. Husmann, W. 1954. Experimental results of biological purification of different trade waste water. Bull. mens. Cent. belge Etude Docum. Eaux, No. 25, 184-189.

489. Huurneman, A. J. 1954. Costs and design for a spray irrigation installation at the co-operative dairy in Vorden. Landbouwkund. Tijdschr., 66:675.

490. Hurrneman, J. 1955. Spraying in practice. The experience of the co-operative dairy at Vorden. Off. Org. Koninkl. Ned. Zuivelb. F. N. Z., 47:(49)887-888.

491. Hyde, C. G., and Rawn, A. M. 1943. Developments in sewerage and sewage treatment. A review of progress and change during 1942. Wat. Wks. Sewer., 90:41.

492. Hyde, C. G., Gray, H. F., and Rawn, A. M. 1941. Report upon the collection, treatment, and disposal of sewage and industrial wastes of the East Bay cities, California. Publ. Hlth. Eng. Abstr., 21:(12).

493. Ichikawa, Y., and Asaka, J. I. 1968. Microbial decomposition of alkylbenzenesulphonate. Biol. Abstr., 49:7, 156.

494. Ihl, A., and Sedlmayer, H. 1966. Influence of quaternary ammonium bases (quats) on the 5-day biological oxygen demand of brewery waste water, and the biological decomposing ability of quats in brewery waste water. Chem. Abstr., 64:3, 194.

495. Ihlow, F., and Mainzer, I. H. 1957. Production of certified milk obtained from cows fed forage from sewage-irrigated fields near Berlin. Milchwissenschaft, 12:(2)50-55.

496. Imhoff, K. 1941. Trickling filter with recirculation for treatment of milk trade waste waters. Gesundheitsingenieur, 64:367.

497. Imhoff, K., and Fair, G. H. 1956. Sewage treatment. 2nd Edition. John Wiley, New York, 1-338.

498. Imhoff, K., Muller, W. J., and Thistlethwayte, D. K. B. 1956. Disposal of sewage and other waste-borne wastes. Butterworth, London, 1-347.

499. Igram, W. T. 1956. A new approach to trickling filter design. J. San. Engr. Div., Amer. Soc. Civil Engr., 82:SA3, 999.

500. Ingram, W. T. 1959. Experimental treatment plant at Dutch Hallow Foods, Inc., at Honeoye Falls, New York. N. Y. State Water Poll. Cont. Bd., Res. Rept. 3.

501. Ingram, W. T. 1959. An investigation of the mechanism of controlled filtration. Sewage ind. Wastes, 31:1147.

502. Ingram, W. T. 1961. Trickling filter treatment of whey wastes. J. Wat. Poll. Cont. Fed., 33:(8)844-855.

503. Ingram, W. T., and New York University, College of Engineering. 1959. Efficiency of various methods of treatment, milk plant wastes, New York State. N. Y. St. Wat. Pollut. Control Bd. Res. Rep. No. 2, 1-144.

504. Ingram, W. T., and Work, H. K. 1958. Efficiency of various methods of treatment of milk plant wastes, New York.State. College of Engineering, New York University, 1-138.

505. Isaac, P. C. G. 1953. Public health engineering. E. and F. N. Spon Limited, London, 1-296.

506. Isaac, P. C. G. 1960. Waste treatment. Proceedings of the 2nd symposium on the treatment of waste waters. Pergamon Press, New York, 1-450.

507. Isaac, P. C. G., and James, A. 1964. Some apsects of the biology of trickling filters. Sb. vys. Sk. chem.-technol. Praze, Technol. Vod., 8:(Pt.1) 123-134.

508. Ishimatsu, M. 1939. Fermentation of monosaccharides with sewage and activated sludge. Mitt. med. Akad. Kiot., 27:403.

509. Jackson, R. H., and Watrous, G. H. 1955. Newer concepts of dairy waste disposal. J. Dairy Sci., 38:231.

510. Jakubowska, L. 1968. Fatty acids in the water of Lake Zegrazynskie. Pr. Inst. gospod. Wodn., 5:(1)83-111.

511. James, F. 1957. How to set-up a dairy waste system. Milk Plt. Mon., 46:(8)16-18.

512. James, G. V. 1965. Water treatment. A quide to the treatment of effluents purification, 3rd Edition. The Technical Press Ltd., London, 1-320.

513. Januszko, M. 1967. Biological analysis of strongly charged bacteria bed in the milk farm at Szaflary. Biol. Abstr., 48:3, 601.

514. Jasewicz, L., and Porges, N. 1956. Biochemical oxidation of dairy wastes. VI. Isolation and study of sludge microorganisms. Sewage ind. Wastes, 28:1130-1136.

515. Jasewicz, L., and Porges, N. 1957. Aeration of whey wastes. Purification and sludge oxidation. Abstr. Pap. Amer. Chem. Soc., 7V.

516. Jasewicz, L., and Porges, N. 1958. Aeration of whey wastes. I. Nitrogen supplementation and sludge oxidation. Sewage ind. wastes, 30:555-561.

517. Jasewicz, L., and Porges, N. 1959. Whey preservation by hydrogen peroxide. J. Dairy Sci., 42:1119.

518. Jasewicz, L., Porges, N., and Hoover, S. R. 1953. Borax as a preservative of dairy waste for the BOD test. Proc. 8th Ind. Waste Conf., Purdue Univ., 387-392.

519. Jeffrey, E. A., and Morgan, P. F. 1959. Oxygen demand of digested sludge liquor. Sewage ind. Wastes, 31:20-22.

520. Jenkins, S. H., and Wilkinson, R. 1940. The oxidation of lactose by activated sludge. J. Soc. Chem. Ind., 59:125-128.

521. Jens and Heinemann. 1959. Treatment of dairy effluent in fish ponds. Molkerei - v. Kasereiztg 10 (12) 353-356. (In German)

522. Jens and Heinemann. 1960. Treatment in fishponds of waste waters from the milk industry. Chem. Zbl., 131:15, 867.

523. Jens, E. C. 1946. Factors relating to milk waste disposal. Proc. St. Coll. Wash. Inst. Dairying, 32-39.

524. Jens, H., Hartmann, S., Andersen, K., Fisker, A., and Andersen, E. 1945. Purifying effluent water. Beretn. Forsogsmejeri, Kbh., No. 46.

525. Jepsen, A., and Roth, H. 1950. Parasitological and bacteriological problems of sewage, with special reference to the artificial-rain process. Nord. Vet Med., 2: 967-991.

526. Jeris, J. S., and Cardenas, R. R. 1966. Gluose disappearance in biological treatment systems. Appl. Microbiol., 14:(6)857-864.

527. Jersey Sewage Board. 1963. Second report on the operation of the Bellozanne waste conversion and sewage treatment works.

528. Jevreinova, T. N., and Jermochina, T. M. 1959. The lipids of waste water. Chem. Zbl., 130:5, 926.

529. Johansson, S., and Buhrgard, A. B. 1966. Separation of butter wash water. 17th Int. Dairy Congr., E/F 757-762.

530. Johnson, F. E. 1967. Dairy waste spray irrigation system. 15th Ann. Dairy Engng. Conf., Michigan State University.

531. Johnson, H. R. 1947. Practical approach to the handling of milk plant waste. Proc. St. Coll. Wash. Inst. Dairying, 117-141.

532. Johnson, W. H. O., and Woods, C. E. 1964. Colorimetric determination of proteins and free amino acids. Wat. Sewage Wks., 111: Ref. No., R. 339-R. 342.

533. Johnson, W. S. 1946. Workshop on milk wastes. Proc. 2nd Int. Waste Conf., Purdue Univ., 121.

534. Johnson, W. S. 1948. An aeration plant for milk-waste disposal. Proc. 4th Ind. Waste Conf., Purdue Univ., 54-62.

535. Johston, B. Research Council of Ontario. Third annual report, 1950-1951. Research Council, Toronto, Ontario, 1-52.

536. Jonas, V. 1948. The preparation of materials rich in proteins from waste waters from agricultural industries with the simultaneous purification in the waste waters. Report 7th International Congress of Agricultural Industries, Paris, Vol. I. 03-N (II).

537. Jonas, V. 1951. Treatment and utilization of waste waters from the food industry. Chem. Zbl., 122:II, 1,797.

538. Jonas, V. 1952. Purification and utilization of dairy sewage. Prum. Potravin, 3:265-268.

539. Jonas, V. 1957. Equipment for continuous purification of waste waters. French patent 1, 143, 647.

540. Jones, G. A., Cheng, K. J., and Gibson, D. L. 1968. What is the significance of coliform contamination of pasturized products? Can. Dairy Ice Cream J., 47:(4)15.

541. Jones, R. H. 1967. Liquid-solids separation in domestic waste with a cationic polyelectrolyte. Diss. Abstr., 28:(B)1553-1554.

542. Joyce, F. 1968. Processor using novel waste technique. Can. Fd. Ind., 39:(1)30-31.

543. Jursik, F. 1960. Proteins in sludge and in supernatant liquor. Sci. Pap. Inst. Chem. Technol., Prague, Fac. Technol. Fuel Wat., 4:Pt. 2, 435-445.

544. Jursik, F. 1960. Protein and amino acids in effluents. Sci. Pap. Inst. chem. Technol., Prague, Fac. Technol. Fuel Wat., 4:Pt. 1, 221-249.

545. Jursik, F. 1961. Some biochemical methods used in the analysis of water. Sci. Pap. Inst. chem. Technol., Prague, Fac. Technol. Fuel Wat., 5:Pt, 2, 241-266.

546. Kägi, F. 1948. Feeding value and money value of creamery waste-products. Schweiz. Zbl. Milchw., No. 2.

547. Kahn, L., and Wayman, C. 1964. Amino acids in raw sewage and sewage effluents. J. Wat. Poll. Cont. Fed., 36:1368-1371.

548. Kannemeyer, A. 1956. Unobjectionable methods for disposal of dairy wastes. Dte. Molk.-Ztg., 77:1197.

549. Kannemeyer, A. 1958. Satisfactory purification of dairy wastes by the activated sludge method. Molk.-u. Kas.-Ztg., 9:(7)187-190.

550. Karp, N. S. 1969. Development of an acceptable electrodialyzed whey product for use in the treatment of chronic uremia. A thesis on file at Ohio State University.

551. Kastens, M. L., and Baldauski, F. A. 1952. Chemicals from milk. Ind. Engng. Chem., 44:1257-1268.

552. Kats, W. 1963. The determination of chemical oxygen demand. Water, 47:191-194.

553. Keiling, J. 1956. Waste water problems in the dairy industry. Chem. Zbl., 127:5, 151.

554. Keiling, J., Massaux, L., and Casalis, J. 1939. The problem of waste waters from milk, butter, and cheese factories. C. R. VI. Congr. int. tech. chim. Ind. Agric., Bp., 2:469.

555. Kempa, E. 1966. Treatment of small amounts of food industry wastes with activated sludge. Chem. Abstr., 65:16, 669.

556. Kempton, L., and Roskopf, R. F. 1967. Operator ingenuity saves cash in State Center, Iowa. J. Wat. Poll. Cont. Fed., 39:(1)128.

557. Kendall, T. R. 1940. Cheese-whey removal, Monroe, Wisconsin. Amer. City, 55:(1)49.

558. Khurody, D. N. 1953. Disposal of milk washings and waste water from large dairies under tropical conditions for growing of fodder crops. 13th Int. Dairy Congr., 3:960-961.

559. Kiermeier, F. von, and Wullerstorff, B. U. 1963. Uber Einflusse auf die Molkenabagabe von Kasebruch. Milchwissenschaft, 18:75-79.

560. Kiker, J. E. 1953. Waste disposal for dairy plants. Sanitarian, Los Angeles, 16:(1)11-17.

561. Kimberly, A. E. 1916. The disposal of wastes from the dairy industry. Ohio Public Health Journal, Ohio State Board of Health, 1-36.

562. King, H. R. 1955. Oxygen absorption in spiral flow tanks. III. Application of formulas. Sewage ind. Wastes, 27:(10)1123.

563. Kipp, R. J. 1965. Glucose utilization by a floc-forming bacterium. Thesis on file, Univ. of Wisconsin.

564. Kirchoffer, W. G. 1944. Milk wastes recirculated on trickling filter. Sewage Wks. Engng., 15:642.

565. Kiss, P., and Timar, J. 1963. Problems of the purification of dairy effluent. Tejipar, 12:(1/2)6-12.

566. Klassen, C. W. 1943. Illinois war industries utilize and treat wastes. Sewage Wks. Eng. and Munic. Sanit., 14:372.

567. Klein, A. H. 1958. Operating problems of industrial waste treatment plants. Sewage ind. Wastes, 30:1379-1398.

568. Kobel, H. 1967. Constitution and characteristics of surface-active substance. V. The effect of the position of a quaternary carbon atom on the biodegradability of alkylbenzene sulphonates. Tenside, 4:33.

569. Koehler, M. 1967. Investigations on the microbial decomposition of detergents. Fortschr. Wasserchem. Grenzgeb., No. 5, 313-322.

570. Kohler, M. 1967. Experiments on the microbial decomposition of detergents. Fortschr. Wasserchem. Grenzgeb., No. 5, 313-322.

571. Kohlins, W. D., and Demarest, E. L. 1950. Waste utilization and disposal systems. Chem. Engng. Progr., 46:597-600.

572. Kolaczkowski, S., Mejboum, Z., and Spandowska, S. 1965. The BOD of some organic substances. Fortschr. Wasserchem. Grenzgeb., No. 3, 113-116.

573. Komolrit, K., and Gaudy, A. F., Jr. 1966. Biochemical response of continuous flow activated sludge processes to qualitative shock loadings. J. Wat. Poll. Cont. Fed., 38:(1)85-101.

574. Komolrit, K., Goel, K. C., and Gaudy, A. F., Jr. 1967. Regulation of endogenous nitrogen supply and its possible applications to the activated sludge process. J. Wat. Poll. Cont. Fed., 39:(2)251.

575. Kormanik, R. A. 1968. A resume of the anaerobic digestion process. Wat. Sewage Wks., 111:R154-R166.

576. Koser, A. 1954. Problems of vetinary hygiene in the treatment of sewage on land. Gesundheitsingenieur, 75:392-395.

577. Koser, A. 1955. Tuberculosis and sewage hygiene. Zbl. Bakt., I, Ref., 157:355-356.

578. Koser, A. 1960. Agricultural utilization of sewage with special reference to veterinary medical requirements. Ber. AbwassTechn. Verein., 11:(11)104-111.

579. Kosikowski, F. V. 1959. Better cottage cheese. The Milk Dealer, 49:(3)33, 68, 70, 72.

580. Kosikowski, F. V. 1963. The Cornell grit test for determining curd shattering of cottage cheese. Am. Milk Rev., 25:(7)26.

581. Kosman, J. L. 1965. New York state control of milk plant waste disposal. N. Y. State Assn. Milk and Food San., 39th Ann. Rept., 115.

582. Kotze, J. P., Thiel, P. G., and Hattingh, W. H. J. Anaerobic digestion. II. The characterization and control of anaerobic digestion. Wat. Res., 3:459-493.

583. Kountz, R. R. 1952. Punch card data control of dairy waste pilot plant. Abstr. Pap. Amer. Chem. Soc., 35.

584. Kountz, R. R. 1953. Dairy waste treatment pilot plant. Proc. 8th Ind. Waste Conf., Purdue Univ., 382-386.

585. Kountz, R. R. 1954. Great saving in new treatment of waste. Pilot plant operation of new biological oxidation principles proves practical. Milk Pl. Mon., 43:(8)21-22.

586. Kountz, R. R. 1954. Big problem: Dairy wastes. Striking solution: Bio-oxidation. Fd. Eng., 26:89-90.

587. Kountz, R. R. 1954. Simplified dairy waste treatment. Papers presented at the 33rd annual conference for dairy plant operators and milk distributors, Univ. and State Agric. College, Burlington, Vermont, 1-30.

588. Kountz, R. R. 1954. Milk industry report. Proc. 1954 Penn. Clean Streams Conf., Bull. 146, Penn. State Chamber of Commerce.

589. Kountz, R. R. 1955. Biological treatment of sewage and industrial wastes. Vol. I. Aerobic oxidation. Brother J. McCabe and W. W. Eckenfelder, 356.

590. Kountz, R. R. 1955. Dairy waste treatment. J. Milk Fd. Technol., 18:243-245.

591. Kountz, R. R. 1955. Simplified dairy waste treatment. Milk Prod. J., 46:10-11 and 54.

592. Kountz, R. R. 1956. Total oxidation waste treatment. Proc. 3rd Ontario Ind. Waste Conf., 51-54.

593. Kountz, R. R. 1956. Aerobic digestion of dairy wastes. Proc. 5th Southern Munic. Ind. Waste Conf., 238.

594. Kountz, R. R., and Forney, C. 1959. Metabolic energy balances in a total oxidation activated sludge system. Sewage ind. Wastes, 31 31:(7)821.

595. Kountz, R. R., and Nesbitt, J. 1958. Oxidation studies. Publ. Wks., 89:(12)103.

596. Kountz, R. R., and Porges, N. 1956. Dairy waste treatment by aeration. United States Department of Agriculture, ARS-73-16, 1-12.

597. Kountz, R. R., and Villforth, J. C. 1954. Biological oxidation aerators. Proc. 9th Ind. Waste Conf., Purdue Univ., 53-63.

598. Kredict, P. 1955. Spray irrigation of dairy waste waters. Off. Org. Koninkl. Ned. Zuivelb, F. FN Z., 47:(49)883.

599. Kuhlmann, F. 1957. Utilization of milk trade waste waters. Fette u. Seifen, 59:238-239.

600. Kulovana, H., and Pitter, P. 1967. Biodegradation of sucrose fatty-acid surfactants. J. appl. Chem. Abstr., 17:14.

601. Kurtz, L. T. 1970. The fate of applied nutrients in soils. J. Agr. Food Chem., 18:(5)773-780.

602. Lacy, W. J., and Rey, G. 1970. The Federal Water Quality Administration research and development program for pollution control in the dairy industry. Presented at the Whey Utilization Conference.

603. Lafleur, R. A. 1961. The sugar factory pollution abatement in Louisiana - the case history of a drainage basin. Proc. 16th Ind. Waste Conf., Purdue Univ., 212-216.

604. Laiterie des Fermiers Reunis Soc. An. 1961. Treatment of milk trade waste waters. Water Poll. Abstr., 34:317.

605. Lamb, C. B., and Jenkins, G. F. 1952. BOD of synthetic organic chemicals. Proc. 7th Ind. Waste Conf., Purdue Univ., 326.

606. Lamb, M. 1949. Treating industrial wastes by the activated sludge process. Publ. Wks., N. Y., 80:(8)24-26.

607. Lane, L. C. 1955. Disposal of liquid and solid wastes by means of spray irrigation in the canning and dairy industries. Proc. 10th Ind. Waste Conf., Purdue Univ., 508-513.

608. Larkin, W. H. 1951. The New York state water pollution control program in relation to milk wastes. Ann. Rept. N. Y. State Assoc. Milk Sanitarians, 25:65-74.

609. Lashen, E. S., and Booman, K. A. 1967. Biodegradability and treatability of alkylphenol ethoxylates, a class of non ionic surfactants. Wat. Sewage Wks., 114:Ref. No., R. 155-R, 168.

610. Laurie, K. W., and Flynn, K. E. 1962. Effluent disposal trials at Leongatha south. Dairy Fmg. Dig., 9:(2)35-40.

611. Lawton, G. W. 1957. Effect of high sodium chloride concentration on trickling filter slimes. Sewage ind. Wastes, 29:1228-1236.

612. Lawton, G. W., Engelbert, L., Rohlich, G., and Porges, N. 1960. Effectiveness of spray irrigation as a method for the disposal of dairy plant wastes. Univ. of Wis. Engr. Exp. Sta. Res. Rept. No. 15.

613. Lawton, G. W., Breska, G., Engelbert, L. E., Rohlich, G. A., and Porges, N. 1959. Spray irrigation of dairy wastes. Sewage ind. Wastes 31:923-933.

614. Lebedeva, K., and Mironov, A. 1961. New whey product. Dairy Sci. Abstr., 23:587.

615. Leclerc, E. H. 1945. Drinking waters and waste waters. Vaillant-Carmanne, S. A., Liege, 1-384.

616. Leclerc, E. H., and Beeckmans, I. 1949. Waste waters from tanneries, dairies, and metal-pickling plants. Analysis of recent publications. Bull. mens. Cent. Belge Etude Docum. Eaux, No. 5, 279-286, and No. 6, 353-370.

617. Leesement, H. 1968. Irrigation with dairy waste water. Svenska Mejeritidn., 59:(4)558, 560, 562.

618. Leighton, F. R. 1964. The challenge to and the changing role of the chemist in the dairy industry. Aust. J. Dairy Technol., 19:43.

619. Leighton, F. R. 1964. Cost of effluent disposal. Aust. J. Dairy Technol., 19:111.

620. Lembke, A. 1939. The part played by bacteria in the decomposition of dairy waste waters in a septic tank. Zbl. Bakt., II, 101:1-29.

621. Lembke, A. 1956. Biological bases of the removal of dairy waste water. Kieler milchw. ForschBer., 8:(3)305-376.

622. Lengyel, W. 1965. The disposal of waste waters from agricultural and foresty. Wass. Abwass., 46-56.

623. Leonard, F. B. 1969. Experiences with handling whey using reverse osmosis. 17th Ann. Dairy Eng. Conf., Michigan State Univ., 75-82.

624. Levine, M. 1940. The role of the trickling filter in sewage purification. Sewage Wks. J., 12:(6)1062-1076.

625. Levine, M., Nelson, G. H., and Goresline, H. E. 1935. Effect of nature of filling material and dosing cycle on purification of creamery wastes. Iowa Engng. Exp. Sta., Bull. 124, 1-56.

626. Liebmann, H. 1966. The effect of new detergents on fisheries and on the process of self purification. Abwass. Technik, 17:(1)VII.

627. Liedberg, A., and Magnusson, F. 1961. Report from a study trip in West Germany and the Netherlands. Svenska Mejeritidn., 53: 563-564.

628. Linderman, I. E. 1942. Treatment of milk waste, United Milk Products Company, Berne, Indiana. Ind. St. Bd. of Health, Sewage Gas, 5:19.

629. Lindroth, A. 1949. The waste-pool system as purification method. 12th Int. Dairy Congr., 3:Ser. 3, 652-658.

630. Lloyd, G. T., and Royal, L. 1964. Simplified methods for the control of creamery effluent. J. Soc. Dairy Techn., 17:(2)111-113.

631. Loehr, R. C. 1961. Analysis of lipids in sewage, sludge, and industrial wastes. Diss. Abstr., 22:1944-1945.

632. Loehr, R. C., and Higgins, G. C. 1965. Comparison of lipid extraction methods. Int. J. Air Wat. Pollut., 9:55-67.

633. Loehr, R. C., and Kukar, T. J. 1965. Removal of lipids by conventional waste treatment methods. Int. J. Air Water Pollut., 9:479-485.

634. Loehr, R. C., and Ruf, J. A. 1968. Anaerobic lagoon treatment of milking parlor wastes. J. Wat. Poll. Cont. Fed., 40:(1)83.

635. Logan, J. A. 1940. Treatment of dairy wastes. Chem. Abstr., 34:3,855.

636. Logan, J. A. 1958. Oxidation of organic wastes in soil and oil carriage of sewage. Publ. Wks., 89:(12)91.

637. Lombard, W. A. 1966. Requirements for effluents in some overseas countries. J. Proc. Inst. Sew. Purif., 65:262-264.

638. Luven, A. L. V. 1963. Food industry waste problems in Quebec, Canada. Ind. Wat. Wastes, 8:(6)22-29.

639. Lynch, W. O., and Sawyer, C. N. 1954. Physical behavior of syndets. I. Frothing and oxygen transfer. Sewage ind. Wastes, 26:(10)1193-1201.

640. Lytken, E. K. 1969. Annual review of dairy waste water problem cases. 29th Annual Report, Danish Government Experiment Station, Hillerod, Denmark, 62-69.

641. Lytken, E., and Christensen, K. 1970. Preliminary results of comparative investigations on treatment plants for factory effluent. 18th Int. Dairy Congr., I - E. A. 1.2, 13.

642. Maatta, R., Jaarmo, J., and Tikka, J. 1968. Detergents in the sewage of Helsinki. Vesitalous, 9L(2)32-38.

643. MacDonald, A. D., and Redelmeier. W. R. 1967. The economics of alternative methods of whey disposal at southern Ontario cheese factories. Ontario Dept. of Agr. and Food, Parliament Building, Toronto, Ontario.

644. MacDonald, A. D., and Redelmeier, W. R. 1968. Can cheesemakers count on new uses to solve the whey disposal problems? Can. Dairy Ice Cream J., 47:(1)22.

645. MacLaughlin, T., Dietz, J. C., and Schulze, K. L. 1968. Selecting the optimum system for proper treatment of dairy plant wastes. Can. Dairy Ice Cream J., 47:(9)14.

646. Magnusson, F. 1958. Purification of dairy waste waters: Some definitions and methods. Svenska Mejeritidn., 50:(20)275-279, (21)289-291.

647. Magnusson, F. 1958. Disposal of dairy waste waters by spray irrigation. Svenska Mejeritidn., 50:(19)261-267.

648. Magnusson, F. 1959. Present waste problems in the dairy industry Svenska Mejeritidn., 51:303-305.

649. Magnusson, F. 1960. Disposal and purification of dairy effluents in the Netherlands and Great Britain. Svenska Mejeritidn., 52: (36)455-460, (37)467-473, (38)483-490.

650. Magnusson, F. 1961. Dairy waste water treatment. Nord. Mejeritidsskr. 27:(11)208-212.

651. Mahlie, W. S., ed. 1964. Manual for sewage plant operators. 3rd Edition. Lancaster Press, Lancaster, Pennsylvania.

652. Mallory, E. B. 1940. Package delivery waste treatment plants. Wat. Wks. Sewer., 87:102.

653. Mallory, E. B. 1942. The combined complete treatment of medium and high concentration of wastes by parallel interacting, dissimiler processes. Wat. Wks. Sewer., 89:(4)143-155.

654. Maloney, T. E., Ludwig, H. F., Harmon, J. A., McClintock, L. 1960. Effect of whey wastes on stabilization ponds. J. Wat. Poll. Cont. Fed., 32:1283-1299.

655. Manea, G. 1969. Present position in the solution of waste-water problems in the dairy industry. Hidroteh. Gosp. Apel. Met., 14:515-519.

656. Manganelli, R. 1952. Detergents and sewage treatment. Sewage ind. Wastes, 24:1057-1068.

657. Manus, L. J. 1957. Should dairy wastes be converted into by-products or discharged to sewers? J. Wastes Eng., 28:342-344.

658. Marchetti, R. 1966. Pollution of waters, some actual problems. Relations between the surface activity, chemical composition, and toxicity to aquatic life, of synthetic detergents. Association Nationale De La Recherche Technique, 185-218.

659. Marek, E., and Svoboda, M. 1956. Treatment of effluents in dairies. Research in Dairy and Poultry Industry in Czecholsovakia, 65-67.

660. Maris, A. G. 1955. The dairy industry and the waste water problem. Off. Org. Koninkl. Ned. Zuivelb. F. N. Z., 47:(49)863-864.

661. Martin, G. 1941. Extracts from operation reports. Green Bay, Wisconsin (1939-1940). Sewage Wks. J., 13:587.

662. Martin, J. P. 1961. Irrigation by aero-spraying of trade waste waters from establishments classed as dangerous, unhealthy, or troublesome. Eau, 48:36-37.

663. Masek, J. 1943. Contribution to the treatment of milk-trade waste waters. Chem. Zbl., 1:2,019.

664. Mason, H., Schreck, A. G., and Siebel, F. 1946. The biological oxygen demand test in brewing. Proc. Amer. Soc. Brew. Chem., 11:60.

665. Massaux, L. 1944. Treatment of waste waters from dairies, piggeries, distilleries, and abattoirs, and from factories salting meat, of sewage, and of waters containing sugars. French Patent 860, 925.

666. Masselli, J. W., Masselli, N. W., and Burford, M. G. 1965. The effect of industrial wastes on sewage treatment. New Zealing Inter-State Water Pollution Control Federation, Boston, Massachusetts.

667. Matova, B. M., Petrov, P. I., and Krechetov, V. I. 1966. Chem. Abstr., 67:67, 418.

668. Matov, B. M., Petrov, P. I., and Krechetov, V. I. 1967. Reagent conditions in electroflotation clarification of waste waters from a butter-making plant. Chem. Abstr., 67:6, 358.

669. Matulova, D. 1964. Influence of detergents on water algae. Sb. vys. Sk. chem.-technol. Praze, Technol. Vod., 8:(Pt. 2)251-301.

670. McCabe, B. J., and Eckenfelter, W. W., Jr. 1958. Biological treatment of sewage and industrial wastes, Volume 2: Solids-liquid separation and anaerobic digestion. Reinhold, New York, 1-336.

671. McDill, B. M. 1952. Pollution study of the Maumee river basin. Sewage ind. Wastes, 24:(10)1288-1302.

672. McDonald, C. S. 1949. Private correspondence with Dr. Gould.

673. McDonough, F. E. 1968. Whey concentration by reverse osmosis. Fd. Engng., 40:(3)124-127.

674. McDowall, F. H. 1931. Treatment and disposal of dairy waste waters. New Zealand Department of Scientific and Industrial Research, Bull. No. 27.

675. McDowall, F. H. 1934. Dairy factory by-products and drainage wastes. Dairy Research Institute, New Zealand, Publication No. 53, 1-6.

676. McDowall, F. H. 1958. Dairy wastes: Disposal by spray irrigation on pasture land. Dairy Eng., 75:(9)251-254 and 266.

677. McDowall, F. H., and Thomas, R. H. 1961. Disposal of dairy wastes by spray irrigation on pasture land. N. Z. Pollution Advisory Council Publication No. 8, 1-100.

678. McKee, F. J. 1950. Milk waste treatment by aeration. Sewage ind. Wastes, 22:1041-1046.

679. McKee, F. J. 1953. New items in milk waste saving and treatment. Proc. 8th Ind. Waste Conf., Purdue Univ., 132-135.

680. McKee, F. J. 1955. Spray irrigation of dairy wastes. Proc. 10th Ind. Waste Conf., Purdue Univ., 514-518.

681. McKee, F. J. 1956. Spray irrigation of milk wastes. Proc. 3rd Ontario Ind. Waste Conf., 17-22.

682. McKee, F. J. 1957. Dairy waste disposal by spray irrigation. Sewage ind. Wastes, 29:(2)157-164.

683. McKee, F. J. 1965. Dairy waste disposal. Mfd. Milk Prod. J., 56:(9)10.

684. McKee, F. 1966. Evaluation of dairy waste treatment systems. 14th Ann. Dairy Eng. Conf., Michigan State Univ., 1-133.

685. McKinney, R. E. 1962. Microbiology for sanitary engineers. McGraw-Hill Company, New York.

686. McKinney, R. E. 1963. Biological oxidation of organic matter. Proc. 3rd Conference on Biological Waste Treatment, Manhattan College.

687. McKinney, R. E., and Schwinn, D. 1960. Waste treatment for an ice cream plant and restaurant. Publ. Wks., N. Y., 91:(4)82-84.

688. McNicholas, J. 1964. A review of the activated sludge process as operated in Great Britain. Sb. vys. Sk. chem.-technol. Praze, Technol. Vod., 8:(Pt. 1)13-22.

689. Mehls, K. F. H. 1955. The bacterial content of water and processes for its reduction. Molkereizeitung, 9:769-770, 813-814, 910-911, and 939-941.

690. Meinck, F., and Schlichting, H. 1950. Purification of dairy wastes by anaerobic decomposition with sludge. Gesundheitsingenieur, 71:(11/12) 180-184.

691. Meinck, F., Stooff, H., and Kohlschutter, H. 1968. Industrial waste waters. Gustav Fischer Verlag, Stuttgart, 1-756.

692. Meineche, K., Muller, W., and Twempling, H. von. 1961. Purification of dairy sewage in the oxidation trench of Holtzthaleben Wasserwirtsch.-Wasstechn., 11:336-341.

693. Meis, H. 1965. Testing dairy waste water for organisms pathogenic to animals. Freie Univ. Berlin: Inaug.-Diss., 1-35.

694. Menna, M. E. 1966. Yeats in soils spray-irrigated with dairy factory wastes. N. Z. Jl. Agric. Res., 9:(3)576-589.

695. Messer, T. 1969. Enzymes in Calgary to break down cheese whey, Fd. Can., 29:(11)18.

696. Metzler, D. 1952. Industry and city co-operate in sewage treatment. Publ. Wks., N. Y., 83:(1)46-47 and 82.

697. Michalka, J. 1959. Disposal of sewage in rural districts. Zbl. Bakt., I., Ref., 170:354-355.

698. Mickelsen, R. 1967. Estimating the cost of treating dairy plant waste materials. Am. Dairy Rev. 29:(4)36-37.

699. Mickelsen, R. 1967. Dairy wastes and the pollution problem, Mfg. Milk Prod. J., 58:(3)8.

700. Middlebrooks, E. J., Jenkins, D., Neal, R. C., and Phillips, J. L. 1969. Kinetics and effluent quality in extended aeration. Water Res., 3:39-46.

701. Midgley, A. R. 1963. Whey and wood bark wastes made fertile compost. Compost Sci., 4:(1)29.

702. Milk Marketing Board. Summary of results-Cannington creamery.

703. Miller, L. L. 1945. Factors to be considered in the design, construction, and maintenance of a sewage disposal system. J. Milk Fd. Technol., 8:348.

704. Milligan, F. B. 1946. Disposal of dairy wastes. Milk Dir., 35:(8)128, 130 and 132.

705. Mills, E. J., Jr., and Stack, V. T., Jr. 1953. Biological oxidation of synthetic organic chemicals. Proc. 8th Ind. Waste Conf., Purdue Univ., 492-517.

706. Ministry of Agriculture and Fisheries. 1954. The calculation of irrigation need. Ministry of Agriculture and Fisheries, Technical Bulletin No. 4.

707. Ministry of Agriculture, Fisheries, and Food. 1962. Irrigation. Ministry of Agriculture, Fisheries, and Food, Technical Bulletin 138.

708. Ministry of Technology. 1965. Report of the Government Chemist, 1964. H. M. Stationery Office, London, 1-116.

709. Ministry of Technology. 1966. Report of the Government Chemist, 1965. H. M. Stationery Office, London, 1-160.

710. Mishukov, B. G. 1965. Purification of wastes from milk processing enterprises. Chem. Abstr., 63:2,737.

711. Mishukov, B. G. 1965. Performance of a low-pressure aeration tank for biochemical clarification of dairy waste waters. Chem. Abstr., 62:12,889.

712. Mitchell, W. D., and Cassidy, N. G. 1966. Utilization of casein wastes for pasture irrigation. 17th Int. Dairy Congr., E/F 745-752.

713. Mohlman, F. W. 1940. The disposal of sewage and industrial wastes, developments and trends in 1939. Part I. Sewage. WatWks. Sewer., 87:(3)47 and 93.

714. Mohlman, F. W. 1948. Industrial wastes. Possibilities of recovery and utilization. Proc. Amer. Soc. Civ. Engrs., Tech. Pap., 74:1052-1061.

715. Mohlman, F. W. 1948. Recent developments in industrial waste disposal in the U. S. A. Proc. Intern. Ass. theor. appl. Limnol., 10:298-314.

716. Moiseev, S. V. 1949. Experimental investigation of factors hindering the disinfection of water by means of chlorine. Gigiena, USSR, (10) 22-28.

717. Molenaar, A. 1960. Irrigation by sprinkling. FAO Agric. Dev. Pap. No. 65.

718. Monson, R. E. 1953. Industrial wastes influence municipal plant design. Publ. Wks., N. Y., 84:(4)84.

719. Montagna, S. D. 1939. Milk wastes. Munic. Sanit., 10:405.

720. Montagna, S. D. 1940. The treatment of dairy wastes. Sewage Wks. J., 12:(1)108.

721. Montagna, S. D. 1940. Methods and results of activated sludge treatment of dairy wastes. Surveyor, 97:117.

722. Moore, E. 1939. Recent developments in trade waste treatment methods. J. Boston Soc. Civ. Engrs., 26:224.

723. Moore, W. A. 1938. The solubility of atmospheric oxygen in sewage Sewage Wks. J., 10:241.

724. Moore, W. A., and Ruchhoft, C. C. 1951. Chemical oxygen consumed and its relationship to BOD. Sewage ind. Wastes, 23:705.

725. Moore, W. A., Ruchhoft, C. C., and Wattie, E. 1942. Oxidation-reduction studies. I. Oxidation-reduction potentials developed by pure cultures in sewage. Sewage Wks. J., 14:980.

726. Moorrees, G. 1953. Irrigation with waste waters from food industries. Tech. de l'Eau, 7:(77)34-35.

727. Morgan, G. B. 1959. Utilization of nitrogen-containing compounds for the biosynthesis of protein in secondary treatment. Sewage ind. Wastes, 31:1275-1280.

728. Morgan, P. E. 1957. The cost of milk waste treatment. Am. Milk Rev., 19:(6)30, 82, 84, 86, and 101-102.

729. Morgan, P. E., and Baumann, E. R. 1957. Trickling filters successfully treat milk wastes. Proc. Amer. Soc. Civ. Engrs., 83:SA4, Pap. No. 1336.

730. Morris, J. C., and Weber, J., Jr. 1964. Adsorption of biochemically resistant materials from solution. Publ. Hlth. Serv. Publ. No. 999-WP-11, 1-74.

731. Mortenson, E. N. 1954. Sewage treatment. Chem. Abstr., 48:2, 956.

732. Mourges, J., and Maugenet, J. 1969. Methods of estimation and amounts of pollution in waste waters from the food industry. Annls. Technol. agric., 18:(1)45-66.

733. Muers, M. M. 1936. The biological purification of whey solution . J. Soc. Chem. Ind.

734. Muers, M. M. 1953. Experience in the treatment and control of dairy wastes. 13th Int. Dairy Congr., 3:962-965.

735. Muers, M. M. 1955. Effluent disposal at large and small dairies. J. Soc. Dairy Technol., 8:(1)34-40.

736. Muers, M. M. 1965. Experiences in the treatment and control of dairy waste waters. Chem. Zbl., 127:5,431.

737. Muers, M. M. 1963. Utilization of milk by-products: Casein. J. Soc. Dairy Ind., 16:63.

738. Muers, M. M. 1964. Water supply and effluent disposal. Dairy Ind., 29:868.

739. Muers, M. M. 1965. Dairy water conservation and effluent disposal. J. Soc. Dairy Technol., 18:(1)3-14.

740. Muers, M. M. 1968. Waters from the processing of milk and milk products. Wat. Poll. Cont., London, 67:644-654.

741. Muers, M. M. 1968. Effluent treatment and disposal. Dairy Ind., 33:(11)747-751.

742. Mulder, E. G., Lie, T. A., and Woldendorp, J. W. 1969. Biology and soil fertility. Soil biology, Reviews of Research UNESCO, Natural Resources Research IX, Paris, 163-208.

743. Muller, G. 1948. The use of the lactose-fuchin-paper plate for the detection of Bacterium coli, and the meaning of the coli-quotient in milk. Milchwissenschaft, 3:82-83.

744. Muller, K. 1962. Treatment of milk trade waste waters. The waste water treatment plant in Mottierzoth. Veroff. Inst. Siedlungswasserwirtschaft, Hannover, No. 9, 75-88.

745. Muller, K. 1964. Treatment of milk trade waste water by the activated-sludge process. Veroff. Inst. Siedlungswasserwirtschaft, Hannover, No. 15, 35-143.

746. Munton, M. H. B. 1963. A quick method of determining 5-day biochemical oxygen demand of effluent, especially malting effluent. Proc. Congr. European Brew. Cong. Brussels, 497-499.

747. Murdock, H. R. 1951. Industrial wastes. Ind. Eng. Chem., 43:(7) 99A, 100A, 102A.

748. Muskat, J. 1961. Oxidation channels. Ost. Wasserw., 13:49-56.

749. Naito, M., Takamatsu, T., and Fan, L. T. 1969. Optimization of the activated-sludge process-optimum volume ratio of aeration and sedimentation vessels. Wat. Res., 3:433-443.

750. Nehrkorn, A. 1968. Dairy effluent--a review. Zentbl. Bakt. Parasitkde, I. Orig., 205:358-363.

751. Nehrkorn, A., and Reploh, H. 1966. Operational experiences with oxidation channels for the treatment of dairy waste waters. Gesundheitsingenieur. 87:143-146.

752. Neill, D. G. 1948. Waste treatment facilities of the Belle Center creamery and cheese company. Proc. 4th Ind. Waste Conf., Purdue Univ., 45-53.

753. Nelson, G. I. 1942. The effect of North Dakota industrial wastes on sewage treatment processes. Off. Bull. N. Dak. Wat. and Sewage Wks. Conf., 9

754. Nemerow, N. L. 1963. Theories and practices of industrial waste treatment. Addison-Wesley Publishing Co., Inc., 1-572.

755. Neuhaus, G. M. 1957. Waste water problems of the food industry with reference to the proposed water law. Fette u. Seifen, 59: 106-111.

756. Neumeyer. 1959. New treatment plant of the dairy in Bad Bramstedt using the Pista iron process. Ber. AbwassTechn. Verein., (10)304-308.

757. New Zealand Marine Department. 1952. Report of the Inter-Department Committee on the pollution of waters in New Zealand. Technical Publications Ltd., Wellington, 1-40.

758. Nichols, C. M. 1940. The installation and operation of a dairy wastes treatment plant. Proc. N. J. Sewage Wks. Assoc., 67-73.

759. Nichols, M. S. 1939. Uses and abuses of the biochemical oxygen demand. Sewage Wks. J., 11:918.

760. Niles, A. H. 1950. Sewage and industrial wastes--1949 in review. Wat. Sewage Wks., 97:47-56.

761. Nilsson, G. 1951. Precipitation of protein in whey by lignin from sulphite waste liquor. Chem. Abstr., 45:5, 732.

762. Nolte, E. 1951. Treatment and disposal of waste waters from beet-sugar factories and the milk industry. Gesundheitsingieur, 72:291.

763. Nolte, E. 1956. New developments in dairy waste treatment. Molkereizeitung, 10:519, 551.

764. Nolte, E., and Bandt, H. J. 1947. Experiments on the treatment of various industrial waste waters and their constituents by the Magdeburg P process. Beitr. Wass. Abwass. Fischereichem, 15-35.

765. Obation, J. 1966. Problems of dispersion of dairy effluent by crop spraying. Compt. Rend.-Acad. Agr. France, 52:(12)932-939.

766. Oborn, J. 1968. A review of methods available for whey utilization in Australia. Aust. J. Dairy Technol., 23:131.

767. O'Connell, W. J., and Fitch, K. 1950. Water disposal. Fd. Ind., 22:71-78.

768. O'Connell, W. J., and Gray, H. F. 1944. Emergency land disposal of sewage. Sewage Wks. J., 16:729.

769. Oeming, L. F. 1947. Treatment and control methods for industrial wastes. Wat. Sewage Wks., 94:105.

770. Oeming, L. F. 1948. Milk waste treatment at the Detroit creamery company condensery, Ovid, Michigan. Sewage Wks. J., 20:(3)512-515.

771. Ohio Department of Health. 1946. Suggestions relative to design of conventional type waste treatment devices, small dairy products plants.

772. Ohio Department of Health. 1954. Ohio Water Pollution Control Board legal manual.

773. Ohio Water Pollution Control Board. 1953. Clean waters for Ohio. The Ohio Water Pollution Control Board Spring Publication, 1-17.

774. Okey, R. W., and Stavenger, P. L. 1967. Membrane technology: A progress report. Ind. Wat. Eng., 4:36-39.

775. Olin, H. L., Box, R. J., and Whitson, R. E. 1942. Bentonite as a coagulant for sewages and industrial wastes. WatWks. Sewer., 89: (12)535-538.

776. Olson, F. W. 1948. Froth and foam. The Digester, Illinois Dept. Publ. Hlth., 11:15-18.

777. Olson, O. O., Heuvelen, W. V., and Vennes, J. W. 1968. Combined industrial and domestic waste treatment in waste stabilization lagoons. J. Wat. Poll. Cont. Fed., 40:214-222.

778. Ontario Research Foundation. 1955. Annual report. Ontario Research Foundation, 1-36.

779. Ontario Water Resources Commission. 1970. Study into the feasibility of locating a whey drying plant in the Stirling area.

780. Otten, H. 1955. Five years of spray irrigation with dairy wastes. Molk.-u. Kas.-Ztg., 6:1, 503.

781. Overholt, V. 1921. A simple septic tank for the farm. Ohio State Univ. Agr. Coll. Ext. Ser., 17:(11).

782. Owen, L. J. 1963. Water use in manufacturing, 1963: Subject statistics. Bureau of Census, Industry Division, MC63 (1)C11-10.

783. Painter, H. H., Denton, R. S., and Qvarmby, C. 1968. Removal of sugars by activated sludge. Wat. Res., 2:427-447.

784. Panina, B., and Nives, M. 1968. Effect of low concentrations of surfactants on sedimentation and filtration. Chem. Abstr., 69:1223-1224.

785. Parabrahmam, M., Lakshminarayana, J. S. S., and Mohanyro, G. J. 1963. Photosynthetic oxygenation of dairy wastes. Proceedings of Symposium on Waste Treatment by Oxidation Ponds, Central Public Health Engineering Research Institute, Nagpur, India.

786. Parashar, D. R. 1965. Treatment of sugar factory effluents-self-oxidation and purification. Indian Sug., 15:325-333.

787. Parker, A. 1941. Treatment of sewage and certain trade waste waters by a new system of alternating double filtration. Inst. Chem. Engr. Trans., 19:82.

788. Parsons, W. A. 1965. Chemical treatment of sewage and industrial wastes. National Lime Assn., Washington, D.C., 1-139.

789. Pasveer, A. 1959. J. Proc. Inst. Sew. Purif., 4:436.

790. Pasveer, A. 1959. Waste treatment. Proceedings of the 2nd Symposium on Treatment of Waste Waters, Univ. of Durham, 117.

791. Pasveer, A. 1960. New developments in the application of the Kessener brushes (aeration rotors) in the activated sludge treatment of trade waste waters. Waste Treatment, Pergamon Press, Oxford, 126-155.

792. Pasveer, A. 1965. Proceedings of the International Conference on the utilization and disposal of potato wastes. Frederickton, New Brunswick Research and Productivity Council, p. 54.

793. Patterson, S. J. 1967. Synthetic detergents in the sewage works. Effl. Wat. Treat. J., 7:201-204 and 231.

794. Paul, U. 1969. Plant for biological purification of effluent in a central diary. Wass. Luft Betr., 13:(3)89-92.

795. Paulik, M., Grunwald, A., Mach, M., and Sztraka, A. 1967. Common biological treatment of malt-house and dairy wastes. Sb. vys. Sk. chem.-technol. Praze, Technol. Vod., 11:35-41.

796. Pawlaczyk, M. 1965. Phenol-degrading micro-organisms and some of their ecological features. Zesz. nauk. Politech. wrocl., No. 108, Inzyn. sanit. 7:1-56.

797. Pepinsky, J. B., Porges, N., and Hoover, S. R. 1956. Application of a rapid chemical oxygen demand test for determining organic pollutions. Proc. 6th Ind. Waste Conf., Purdue Univ., 367-374.

798. Peremans, L. 1965. The problem of water in the dairy industry. Trib. Centr. belge Etude Docum. Eaux, 18:425-429.

799. Pester, A. 1959. Regulations concerning the dairy effluent and its disposal from dairies. Dte. Molk.-Ztg., 80:(28)1247-1250.

800. Pester, A. 1959. Treatment of dairy wastes--a technical problem. Molk.-u. Käs.-Ztg., 10:(27)981-984.

801. Pester, A. 1959. Dairy waste treatment as a dairy processing problem. Molk.-u. Käs.-Ztg., 10:298.

802. Petru, A. 1968. Combined treatment of cotton mill and dairy wastes with sewage. Wat. Wastes Treatm. J., 11:532-533.

803. Pettet, A. E. J. 1957. Water pollution. Soc. Chem. Ind., London, 1-164.

804. Phelps, E. G., and Tiedeman, W. D. 1950. Public health engineering. The food contact. John Wiley and Sons, Inc., New York, Vol. II, Part 3.

805. Pickett, A. 1943. Dairy wastes: Presenting screen-chamber plan for dairies connected to sanitary sewers. Publ. Hlth. Eng. Abstr., 23:(4,5,6)15.

806. Pien, J. 1952. Dairy waste waters. Bull. mens. Cent. belge Etude Docum. Eaux, 3:(22)30.

807. Pien, J. 1952. Purification of waste waters from dairy plants. Industr. lait., (64)10-16, (66)53-61, (68)102-113, (70)153-160.

808. Pien, J. 1952. Purification of waste water from dairy plants. Industr. lait., (75)267-279.

809. Pien, J. 1953. The problem of waste water in the dairy industry. 13th Int. Dairy Congr., 3:970-974.

810. Pien, J. 1954. Towards the solution of the problem of dairy wastes. Industr. lait., (92)111-117.

811. Pien, J. 1954. Biological destruction of lactoserum. Bull. mens. Cent. belge Etude Docum. Eaux, (24)133-137.

812. Pien, J. 1954. Measurement of the self-purifying capacity of water courses. Bull. mens. Cent. belge Etude Docum. Eaux, (26)249-253.

813. Pien, J. 1954. Treatment and disposal of industrial effluents. J. Inst. Brewing, 60:443.

814. Pien, J. 1956. Solution of the problem of dairy industry waste waters. Chem. Zbl., 127:5,432.

815. Pipes, W. O. 1962. pH variation and BOD removal in stabilization ponds. J. Wat. Poll. Cont. Fed., 34:(11)1140.

816. Pitter, P. 1964. Surface-active agents in waste waters. VIII. Relationship between molecular structure and the susceptibility of anion-active surfactants to biological oxidation. Summary of results. Sb. vys. Sk. chem.-technol. Praze, Technol. Vod., 8:(Pt. 2)13-39.

817. Pitter, P. 1968. Relationship between molecular structure and the biodegradability of surfactants and their metabolism. Sb. vys. Sk. chem.-technol. Praze, Technol. Vod., 14:47-137.

818. Pitter, P., Frank, J., and Chlumova, J. K. 1964. Surface-active agents in waste waters. VII. The influence of surfactants on the anaerobic sludge digestion. Discontinual laboratory experiments. Sb. vys. Sk. chem.-technol. Praze, Technol. Vod., 8:(Pt. 1)

819. Pittman, E. E., and Bottoms, R. R. 1941. Treatment of milk wastes. Fd. Ind., 13:(12)97.

820. Placak, O. R., and Ruchhoft, C. C. 1947. Studies of sewage purification. XVII. The utilization of organic substrates by activated sludge. Sewage Wks. J., 19:423.

821. Platon, B., and Thome, K. E. 1945. Experiments concerning the treatment of waste waters from dairies. Medd. Statens Mejeriforsok, No. 15.

822. Poole, B. A. 1947. Report of the 1946 situation with reference to wastes from Indiana food-processing industries. Proc. 3rd Ind. Waste Conf., Purdue Univ., 240-243.

823. Popescu, V., Mihail, M., and Musetescu, P. 1966. Studies on dairy waste waters. Studii Prot. Epur. Apel., Buc., 7:237-263.

824. Popovic, M., and Popovic, I. B. 1969. Biological filtration in laboratory studies of waste water purification in the dairy industry. II. Retention time of waste water in the bacterial bed as a factor in purification. Chem. Abstr., 71:(14)205.

825. Porges, N. 1956. Bio-oxidative treatment of dairy wastes. Proc. 3rd Ontario Ind. Waste Conf., 55-61.

826. Porges, N. 1956. Waste treatment by optiman aeration-theory and practice in dairy waste disposal. J. Milk Fd. Technol., 19:(2) 34-38.

827. Porges, N. 1958. Practical application of laboratory data to dairy waste treatment. Fd. Technol., 12:(2)78-80.

828. Porges, N. 1958. Dairy wastes: Disposal by balanced, biochemical bio-oxidation. Dairy Eng., 75:(9)255-258, (10)294-297.

829. Porges, N. 1960. Dairy waste treatment by aeration: Theory, design, construction, operation. U.S.D.A., Agr. Handbook 176.

830. Porges, N., and Hoover, S. R. 1949. Treatment of dairy waste by aeration. I. Methods of study. Proc. 5th Ind. Waste Conf., Purdue Univ., 130-136.

831. Porges, N., and Jasewicz, L. 1959. Aeration of whey wastes. II. Chemical oxygen demand (COD)-solids balance. Sewage ind. Wastes, 31:(4)443-446.

832. Porges, N., Jasewicz, L., and Hoover, S. R. 1952. Measurement of carbon dioxide evolution from aerated sludge. Sewage ind. Wastes, 24:(9)1091.

833. Porges, N., Jasewicz, L., and Hoover, S. R. 1953. A microbiological process report. Aerobic treatment of dairy wastes. Appl. Microbiol., 1:(5)262-270.

834. Porges, N., Jasewicz, L., and Hoover, S. R. 1955. Biochemical oxidation of dairy wastes. VII. Purification, oxidation, synthesis and storage. Proc. 10th Ind. Waste Conf., Purdue Univ., 135-146.

835. Porges, N., Pepinsky, J., Jasewicz, L. 1951. Feed yeasts from dairy by-products. J. Dairy Sci., 34:(6)615-621.

836. Porges, N., Pepinsky, J. B., Hendler, N. C., and Hoover, S. R. 1950. Biochemical oxidation of dairy wastes. II. Comparative study of yeasts. Sewage ind. Wastes, 22:888-892.

837. Porges, N., Pepinsky, J., Jasewicz, L., and Hoover, S. R. 1952. Biochemical oxidation of dairy wastes. III. Failure of sodium nitrate as a source of oxygen. Sewage ind. Wastes, 24:(7)874-881.

838. Porges, R. 1963. Industrial waste stabilization ponds in the United States. J. Wat. Poll. Cont. Fed., 35:(4)456.

839. Porges, R., Harlow, G. L., Struzeski, E. J., and Morris, G. L. 1961. Stabilization ponds for treatment of industrial wastes. U. S. Public Health Service, Robert A. Taft Sanitary Engineering Center Tech. Rept. W61-29.

840. Posthumous, G. 1955. The waste water problem in dairy plants and the technical division of the cooperatives. Off. Org. Koninkl. Ned. Zuivelb. F. N. Z., 47:(49)889.

841. Poulson, P. R., Lind, C., and Anderson, K. P. 1953. Analysis of spetic tank treatment of dairy waste disposal. State Exp. Sta. Creamery, Hillerod, Denmark, Bull. 79, 38.

842. Poulson, P. R., Rasmussen, H. S., and Anderson, K. P. 1953. Experiments with sprinkling of dairy waste. Exp. Sta. Creamery, Hillerod, Denmark, Bull. 79, 9.

843. Povoledo, D., and Gerletti, M. 1962. Colorimetric determination of protein in fresh water by a modification of the Lowry-Folin phenol reagent method. Mem. Inst. Ital. Idrobiol. de Marchi, 15:153-166.

844. Power, R. M. 1955. Treatment of dairy waste by aeration. Sanitalk, 3:(4)2-3.

845. Power, R. M. 1963. Small extended aeration activated sludge treatment plants in Massachusetts. Publ. Hlth. Eng. Abstr., 43:635.

846. Prasse, P. E. 1956. Waste disposal at the dairy cooperative at Medermormter-Itonnepel. Molk.-u. Käs.-Ztg., 7:851.

847. Prasse, P. E. 1958. Spraying of dairy wastes. Molk.-u. Käs.-Ztg., 9:93.

848. Prasse, P. E. 1962. Costs of discharging waste water to public sewers. Molkereizeitung, 16:921.

849. Prescott, S. C., and Dunn, C. G. 1940. Industrial microbiology. McGraw-Hill Book Company, Inc., 1-552.

850. Pretorius, W. A. 1969. Anaerobic digestion. III. Kinetics of anaerobic fermentation. Wat. Res., 3:545-558.

851. Preuss, F. 1952. The treatment of milk trade waste waters. Wass. u. Boden, 4:272.

852. Preuss, F. 1953. Treatment of dairy waste waters by an artificial biological method. Molk.-u. Käs.-Ztg., 4:908-1025.

853. Prüss, M. 1939. Recovery of materials in the treatment of trade waste waters. Rev. univ. Min., 5:630.

854. Putnam, G. W. 1949. Progress on waste prevention. Proc. 5th Ind. Waste Conf., Purdue Univ., 418.

855. Pytlik, R., and Svec, Z. 1954. Purification and utilization of dairy wastes in fish ponds. Sb. csl. Akad. Zemed. ved., 27 (Series B):(2/3) 177-198.

856. Quest, H. 1958. Principles of the treatment of milk trade waste waters. Molk.-u. Käs.-Ztg., 9:750-754.

857. Quest, H. 1962. Problems in waste water technique. Molkereizeitung, 16:1635.

858. Rahn, O. 1956. Protein feed from aerated sewage and whey. Chem. Abstr., 50:12,350.

859. Rainbow, C., and Rose, A. H. eds. 1963. Biochemistry of industrial micro-organisms. Academic Press, New York, 1-708.

860. Raison, M. 1966. Treatment of waste waters by froth flotation. Association Nationale de la Recherche Technique, Paris, 169-184.

861. RamaRao, C. V., Speece, R. E., and Engelbrecht, R. S. 1965. The response of activated sludge to nitrogen deficient conditions. J. Wat. Poll. Cont. Fed., 37:(10)1422-1436.

862. Randolph, H. E., and Harper, W. J. 1960. Factors affecting the total lactic acid concentration of cottage cheese. Presented at 55th Annual Meeting of the American Dairy Science Association.

863. Rao, B. S., and Gaudy, A. F., Jr. 1966. Effect of sludge concentration on various aspects of biological activity in activated sludge. J. Wat. Poll. Cont. Fed., 38:(5)794-812.

864. Raschke, R. L. 1968. The algae in a milk waste stabilization pond. Iowa St. J. Science, 42:(4) 325-333.

865. Rausing, G. 1970. Packaging systems, waste disposal, and the problems of litter. 18th Int. Dairy Congr., I - E, A. 4.14, 469.

866. Rehm, L. F., and Kirk, F. N. V. 1964. San-Jose-Santa Clara kraus process plant copes with variable canning load. WatWks. Wastes Engng., 1:(7)32-36, and 70-72.

867. Reinhold, F. 1955. Anaerobic treatment of dairy waste waters. Gesundheitsingenieur, 76:15-19.

868. Reinsink, J. H. 1963. R. A. A. D. test installation. Halfjaarl. Tijdschr. belg. stud. document. Centre. Wat., No. 12, 44-46.

869. Rensink, J. H. 1966. Effect of releasing dairy waste into surface waters. Water, 50:(7)99-102.

870. Rensink, J. H. 1966. Combating of Sphaerotilus natans in activated sludge by chlorine. Water, 50:5-8.

871. Renwick, R. S. 1963. Utilization of milk by-products: Skim milk. J. Soc. Dairy Ind., 16:50.

872. Reploh, H., and Kustermann, H. 1958. Buffering action of alkalin industrial waste waters and biological decomposition. Gesundheitsingenieur, 79:233-235.

873. Reploh, H., and Nehrkorn, A. 1966. Experience with oxidation trenches: A contribution to dairy effluent hygiene. Arch. Hyg. Bact., 150:(3/4)237-248.

874. Reynolds, D. J. 1966. Methods for estimating the strength of dairy effluents. 17th Int. Dairy Congr., 5:773-780.

875. Rhoads, A. T. 1965. Disposal systems for food processors. Maryland Processors Report, 392-395.

876. Rhoads, J. P. 1949. Treatment plant handles sewage and industria waste. Publ. Wks., N. Y., 80(1)33-34.

877. Rhodes, A., and Fletcher, D. L. 1966. Principles of industrial microbiology. Pergamon, Oxford, 1-370.

878. Richter, H. 1964. New observations on the operation of the final biological treatment of the spent phenosolvan liquor from the VEB lignite-cooking combine at Lauchhammer. LitBer. Wass. Abwass. Luft Boden. 12:108-109.

879. Ries, K. M. 1968. Application of polymers in existing municipal sewage treatment plants. Wat. Sewage Wks., 115:R195-R197.

880. Rinn, M. 1962. Preliminary recommendations for requirements of composition of effluents from dairy plants. Molkereizeitung, 16:1,518.

881. Rinn, M. 1963. Recommendations for the requirements to be met by dairy effluents. Milchwissenschaft, 18:80.

882. Rinn, M. 1965. Detoxication and neutralization of corrosive effluent in dairies, in particular of residues from butyrometers. Dte. Molk.-Ztg., 86:(4)107-109.

883. Rinn, M. 1966. The removal of fat and toxic substances and the neutralization of butyrometer-waste sulphuric acid in the milk trade. Wass. Luft. Betr., 10:674-675.

884. Rippen, A. L., and Burgwald, L. H. 1941. The effect of acidified cans on the quality of dairy products and on the phosphatase value of cream and butter. Milk Plt. Man., 30:(11).

885. Rivers Pollution Prevention Sub-Committee of the Central Advisory Water Committee. 1949. Prevention of river pollution. H. M. Stationery Office, London.

886. Roberts, W. M. 1955. Carnegie Inst. of Washington, Publication No. 607, Washington, D.C.

887. Roberts, W. M. 1964. Water and waste problems and the development of the food industry. Proc. 13th Sth. Munic. Ind. Waste Conf., 163-166.

888. Robertson, R. 1939. Work of the Water Pollution Research Board. Nature, London, 144:118.

889. Robinson, H. 1945. Effluent treatment and solids recovery. III. Protein nitrogen from food industry wastes. Ind. Fibres, Synthetics and By-Products, 7:342,378, and 411.

890. Roi, D. Le. 1950. Disposal of dairy waste waters. Milk Ind., 30:(7)39-43.

891. Romankova, A. G. 1965. Microflora and microfauna of activated sludge used for purifying waste water from a milk combine. Biol. Abstr., 46:1349-1350.

892. Ross, R. D. 1968. Industrial waste disposal. Reinhold Book Corporation, New York, 1-352.

893. Rower. 1955. Treatment of dairy waste by aeration. Sanitalk,

894. Royal, L. 1964. The control of dairy effluent. Milk Ind., 55:(4)36-41.

895. Ruchhoft, C. C., and Kachmar, J. F. 1941. Studies of sewage purification. XIV. The role of Sphaerotilus natans in activated sludge bulking. Sewage Wks. J., 13:3.

896. Ruchti, J., and Kunkler, D. 1966. Enzymatic determination of glucose, fructose and saccharose in waters. Schweiz. Z. Hydrol., 28:62-68.

897. Rudolfs, W. 1949. A critical review of the literature of 1948 on sewage and waste treatment and water pollution. Sewage ind. Wastes, 22:593-653.

898. Rudolfs, W. 1950. A critical review of the literature of 1949 on sewage and waste treatment and water pollution. Sewage ind. Wastes, 22:593-653.

899. Rudolfs, W. 1953. Industrial wastes. Their disposal and treatment. American Chemical Society's Monograph Series No. 118, Reinhold Publishing Corp., New York, 1-506.

900. Rudolfs, W. 1954. Purification of waste waters from the dairy industry in the United States of America. Landbouwkund. Tijdschr., 66:675.

901. Rudolfs, W., Babbitt, H. E. 1944. A critical review of the literature of 1943 on sewage and waste treatment and stream pollution. Sewage Works J., 16:222.

902. Rudolfs, W., and Gehm, H. W. 1946. Coagulant composition for sewage. Chem. Abstr., 40:2,564.

903. Rudolfs, W., and Heukelekian, H. 1952. Biological treatment of industrial wastes. Chem. Eng. Progress, 48:449-454.

904. Ruffer, H. 1966. Waste waters from food industries and the possibilities of treatment. Association Nationale De la Rechercle Technique, Paris, 1-238.

905. Rugaber, J. W. 1951. Operation of a milk-wastes treatment plant employing a trickling filter. Sewage ind. Wastes, 23:(11)1425-1428.

906. Rugaber, J. W. 1952. Milk losses, Proc. 7th Ind. Waste Conf., Purdue Univ., 474-480.

907. Rugaber, J. W. 1952. Sources of milk losses. Butter, Cheese, Milk Prod. J., 43:(9)46-47, 83-84, and 86.

908. Rugosa, M., Browne, H. A., and Whittier, E. O. 1947. Ethyl alcohol from whey. J. Dairy Sci., 30:263.

909. Rumpf, A. 1953. Alternating double filters in England. Gesundheitsingenieur, 74:281-285.

910. Ryan, J. J. 1949. Experiments on the manurial value of creamery sewage. J. Dep. Agric., Eire, 46:29-35.

911. Saal, H. 1959. New whey disposal system. Am. Milk Rev. and Milk Plt. Mon., 21:(4)32-33, 118-119.

912. Sales, H. S., and Bland, J. 1939. England's water problem. Country Life Ltd., London, 1-286.

913. Salplachta, J., and Gillar, J. 1968. Final purification in high trickling filters of effluent from dairy and jam factories. Prum. Potravin, 19:(6)324-330.

914. Salvato, J. A., and Bogedain, F. O. 1966. The disposal of liquid wastes and dairy farms, receiving stations and small plants. 40th Ann. Rept., N. Y. State Assn. Milk and Food San., 174.

915. Sandborg, O. W., and Steffen, A. J. 1947. Saving and disposal of creamery waste. Nat. Butt. Cheese J., 38:(2)34-35, and 62.

916. Sanborn, N. H. 1953. Disposal of food processing wastes by spray irrigation. Sewage ind. Wastes, 25:1034-1043.

917. Sander, P. 1957. Milk trade waste waters and possibilities of treatment and disposal. Ber. AbwassTechn. Verein., 8:146-156.

918. Sanders, M. D. 1947. What can be done with whey? Proc. 3rd Ind. Waste Conf., Purdue Univ., 288-292.

919. Sanders, M. D. 1948. Industrial sanitary engineering in dairy-plant management. Proc. 4th Ind. Waste Conf., Purdue Univ., 63-66.

920. Sarkka, M., Nordlund, J., Pankakoski, M., and Heikonen, M. 1970. Water pollution by Finish dairies. 18th Int. Dairy Congr., I - E, A. 1.2 11.

921. Sassot, M. 1968. Treatment of waste waters in the milk industry. Techq. Eau Assain., No. 256, 55-62.

922. Sassot, M. M. 1968. Waste Water Treatment in the Dairy Industry. Chem. Abstr., 69:45,875.

923. Savage, W. 1941. Practical public health problems. J. and A. Churchill Ltd., London.

924. Sawyer, C. N., Callejas, P., Moore, M., and Tom, A. Q. Y. 1950. Primary standards for BOD work. Sewage ind. Wastes, 22:26-30.

925. Scarlett, C. A. 1939. The practical treatment of dairy effluents. Analyst, 64:252-260.

926. Schaafsma, J. H. A. 1949. The present state of the problem of waste liquids in the dairy industry from a historical, technical, and economic viewpoint. 12th Int. Dairy Congr., 3:Sect. 3, 659-670.

927. Schaafsma, J. H. A. 1949. Waste waters in the dairy industry. Ned. Melk Zuiveltijdschr., 3:142-154.

928. Schaafsma, J. H. A. 1949. Waste liquids in the dairy industry. Neth. Milk Dairy J., 3:(2)142-154.

929. Schaafsma, J. H. A. 1953. Problems of waste water in the dairy industry. 13th Int. Dairy Congr.

930. Schaafsma, J. H. A. 1954. Purification and utilization of dairy waste waters by means of spreading on pastures and arable land. Sewage ind. Wastes, 26:926.

931. Schaafsma, J. H. A. 1957. Demonstration R. A. A. D. purification plant for waste waters at Nutricia Ltd., Zoetermeer. Alg. Zuivelb., 50:306-309, and 330-332.

932. Schaake, W. 1960. The water requirements and waste-water output in the manufacture of industrial products. Wasserwirtsch-Wassertech., 10:291.

933. Schaefer, H. 1966. Isolation of dissolved carbohydrates from sea water. Biol. Abstr., 47:5,165.

934. Schärff, E. 1952. Treatment of milk trade waste waters in Belgium and France. Wass. u. Boden, 4:(1).

935. Scheel, H. A. 1969. Conservation of water. 17th Ann. Dairy Eng. Conf., Michigan State Univ., 83-87.

936. Scheltinga, H. M. J. 1963. Some aspects of the waste water problems of the dairy industry. J. Water, 47:109-113.

937. Scheltinga, H. M. J. 1963. Purification of dairy waste water. Bull. mens. Cent. belge Etude Docum. Eaux, No. 235, 236.

938. Scheltinga, H. M. J. 1966. Proportional sampling of dairy waste water. Pollution figures related to production. 17th Int. Dairy Congr., E/F:767-771.

939. Scheltinga, H. M. J. 1968. Effluent problems in the modern dairy factory. Voed. Tech., 2:(51)1339-1341, and 1343.

940. Scherb, C. 1964. The purification of dairy waste waters. Wasserversorg. u. AbwassTech., 15:Ser. 4, 4-7.

941. Scherb, K. 1959. Difficulties in the assessment of organic waste waters illustrated by the example of milk trade waste waters. LitBer. Wass. Abwass. Luft u. Boden, 8:326-327.

942. Schmittel, H. H. 1969. Semi-industrial scale experiments on biological sewage. J. Molkereizeitung, Hild., 23:(10)283-286.

943. Scholl, O. 1955. Survey of processes for disposal of milk trade waste waters. Dte. Molk.-Ztg., 76:898-901.

944. Scholl, O. 1955. Questions regarding the unobjectionable disposal of dairy wastes. Dte. Molk.-Ztg., 76:261.

945. Scholl, O. 1955. Dairy waste waters and the water courses. Dte. Molk.-Ztg., 76:154.

946. Scholz, H. G. 1962. The five-day BOD value of some organic industrial waste waters. Chem. Abstr., 57:13,562.

947. Scholz, H. G., and Kenda, V. 1963. Oxygen demand of industrial waste liquors. J. Appl. Chem., Lond., Abstr., 13:497.

948. Schonherr, W. 1957. Avoiding forages from sewage-irrigated fields for cows producing certified milk. Michwissenschaft, 12:(11) 435-438.

949. Schonopp, G., and Schaller, A. 1959. The practice of agricultural utilization of sewage. Zbl. Bakt., I, Ref., 173:93.

950. Schraufnagel, F. H. 1957. Dairy wastes disposal by ridge and furrow irrigation. Proc. 12th Ind. Waste Conf., Purdue Univ., 28-49.

951. Schraufnagel, F. H. 1959. Disposal of industrial wastes by irrigation. Publ. Hlth. Rept., Wash., 74:133-140.

952. Schraufnagel, F. H. 1962. Ridge and furrow irrigation for industrial waste disposal. J. Wat. Poll. Cont. Fed., 34:(11)1117.

953. Schroeder, E. D. 1967. Dissimilatory nitrate reduction by mixed bacterial populations. Diss. Abstr., 28:B, 1964.

954. Schroepfer, G., and Ziemke, N. 1959. Development of the anaerobic contact process. I. Pilot-plant investigations and economics. II. Ancillary investigations and special experiments. Sewage ind. Wastes, 31:(2)164, (6)697.

955. Schropp, W. 1953. Experiments concerning the influence of dairy waste waters on the development of plants. 13th Int. Dairy Congr., 3:966-969.

956. Schropp, W. 1960. Use of milk trade waste waters in agriculture. Chem. Zbl., 131:7653.

957. Schropp, W. 1964. Waste water problems in cheese plants. Dte. Molk.-Ztg., 18:349.

958. Schropp, W., and Vogt, K. F. 1966. Utilization of dairy waste in agriculture. 17th Int. Dairy Congr., E/F:735-744.

959. Schua, L. F. 1966. The treatment of waste waters at a condensed milk plant. Wasserwirtschaft, Stuttg., 56:370-372.

960. Schulz, G. 1955. Questions regarding the unobjectionable disposal of dairy wastes. Dte. Molk.-Ztg., 76:129.

961. Schulze, K. L. 1954. Non-clogging foam-safe aerators lick cheese-waste problem. Fd. Eng., 26:(9)51-53.

962. Schulze, K. L. 1954. New developments in dairy waste treatment. Proc. 9th Ind. Waste Conf., Purdue Univ., 231-238.

963. Schulze, K. L. 1955. Experiences with a new type of dairy waste treatment. Sth. Dairy Prod. J., 58:(2)28-29, and 94-96.

964. Schulze, K. L. 1955. Proc. Am. Soc. Civ. Engrs., 81:SA4, Pap. No. 847.

965. Schulze, K. L. 1960. Elements of a trickling filter theory. Conference on Biological Waste Treatment, Manhattan College.

966. Schulze, K. L. 1960. Trickling filter theory. Wat. Sewage Wks., 107:(3).

967. Schulze, K. L. 1960. Load and efficiency of trickling filters. J. Wat. Poll. Cont. Fed., 32:(3)245.

968. Schulz-Falkenhain, H. 1948. Purification of waste waters from dairies. Gesundheitsingenieur, 69:28.

969. Schulz-Falkenhain, H. 1952. Treatment of waste waters from a dairy plant in Grevenbruck. Gesundheitsingenieur, 73:205-206.

970. Schulz-Falkenhain, H. 1954. Treatment of dairy waste waters by spray irrigation on land. Oesterr. Wasserwirt., 12:300.

971. Schulz-Falkenhain, H. 1955. Contributions to the problem of waste waters in the milk industry. Molk.-u. Käs.-Ztg., 6:1060-1062, 1116-1117, 1588-1590, 1610-1611, and 1671-1672.

972. Schulz-Falkenhain, H. 1955. Pathogenic organisms in dairy waste waters. Molk.-u. Käs.-Ztg., 6:388.

973. Schulz-Falkenhain, H. 1956. Contributions to the problem of waste waters in the milk industry. Molk.-u. Käs.-Ztg., 7:62-63, 101-102.

974. Schulz-Falkenhain, H. 1956. Treatment of slaughterhouse and milk industry waste waters. Ber. AbwassTechn. Verein., 7:246-248.

975. Schulz-Falkenhain, H. 1956. Discussion of the dairy waste problem. IX. Treatment in grit chambers. X. Treatment with bar screens and screens. XI. Treatment in fat traps. Molk.-u. Käs.-Ztg., 7:101.

976. Schulz-Falkenhain, H. 1956. Waste waters of the milk industry. Wasserwirtschaft, Stutt., 46:330.

977. Schulz-Falkenhain, H. 1957. Disinfection of waste water. Molk.-u. Käs.-Ztg., 8:255.

978. Schulz-Falkenhain, H. 1957. Waste water treatment with algae in ponds. Molk.-u. Kas.-Ztg., 8:593.

979. Schulz-Falkenhain, H. 1958. The costs of waste water disposal in dairy plants. Molk.-u. Käs.-Ztg., 9:799.

980. Schulz-Falkenhain, H. 1962. Water supply and waste water in dairy plants. Molkereizeitung, 16:366.

981. Schulz-Falkenhain, H. 1962. Charges and contributions for dairy wastes. Molkereizeitung, 16:919.

982. Schulz-Falkenhain, H. 1963. Treatment of dairy waste waters in oxidation ponds. Dte. Molk.-Ztg., 84:1403.

983. Schulz-Falkenhain, H. 1966. Standards for costing effluent disposal. 17th Int. Dairy Congr., E/F:763-765.

984. Schulz-Falkenhain, H. 1970. Basis for the costs of sewage in public sewage treatment. 18th Int. Dairy Congr., I - E, A. 1.2, 17.

985. Schwarzkopf, V. 1951. Reducing milk waste in dairy plants. Milk Dealer, 41:(11)51.

986. Schwarzkopf, V. 1952. Reduction of milk waste in dairy plants. Sewage ind. Wastes, 24:1489-1494.

987. Schweizer, M. 1968. Analysis of waste waters from dairy and cheese plants on the basis of existing literature. Molkereizeitung, 9:254 and 256-257.

988. Schweizer, M. 1968. Studies on effluent from cheese factories. Schweiz. Milchztg (Lait. Romad), 94:(101)820-821.

989. Science and Appliance. 1953. OSU Research Foundation, 17:(3).

990. Scott, J. 1959. Adequate waste disposal facilities for milk processing plants. Can. Dairy Ice Cream J., 38:(7)21.

991. Scott, R. H. 1962. Disposal of high organic content wastes on land. J. Wat. Poll. Cont. Fed., 34:932-950.

992. Seiberling, D. A. 1968. Equipment and process design as related to mechanical-chemical cleaning procedures. Chem. Eng. Progress, 64:(86)94-104.

993. Seidel, K. 1965. Hydrobotanical contributions for the protection of waters. Mitt. Verein. dt. GewassSchutz, 6-8.

994. Seidel, K. 1967. New Ways of biological treatment of waste waters which are difficult to purify. Sug. Ind. Abstr., 29:270.

995. Seiler, A. C. 1969. Orrville, Ohio, improves waste-water treatment plant. Wat. Wastes

996. Seiser, A. 1952. Agricultural utilization of sewage. Off. Gesundh Dienst, 13:402.

997. Semenov, A. D., Ivleva, I. N., and Datsko, V. G. 1965. Microdetermination of reducing sugars in natural water. Analyt. Abstr., 12:Abstr. No. 956.

998. Sharkawi, F. M. E., and Moawad, S. K. 1970. Stabilization of dairy wastes by algal-bacterial symbiosis in oxidation ponds. J. Wat. Poll. Cont. Fed., 42:115-125.

999. Sharratt, W. J. 1961. Whey, its effect on soil and plant growth. Diss. Abstr., 22:(3)691-692.

1000. Sheets, W. D., Dr. Hamdy, Dr. Weiser. 1953. Biological treatment of refinery phenolic wastes.

1001. Shifrin, S. M., and Burtsev, V. P. 1965. Treatments of effluents from cheese-making plants. Chem. Abstr., 64:9,420.

1002. Shifrin, S. M., and Burtsev, V. 1965. Composition of the waste water from a cheese plant. Chem. Abstr., 63:17,675.

1003. Shifrin, S., and Mishukov, B. G. 1968. Purification of dairy effluent. Ochistka stochnykh vod predpriyatii molochnoi promyshlennosti, 1-118.

1004. Shukla, J. P., and Kapoor, B. D. 1962. Stabilization of treated and untreated sugar factory effluents. Sug. Ind. Abstr., 24:212.

1005. Shukla, J. P., and Kapoor, B. D. 1963. Examination of the activated-sludge process for the treatment of sugar factory effluents. Sug. Ind. Abstr., 25:73.

1006. Shuttleworth, R. G. 1952. Effluents from milk processing industries. I. The utilization of whey and buttermilk. II. Their treatment before disposal. Wat. Poll. Abstr., 25:(2)47.

1007. Siddiqi, R. H., Engelbrecht, R. S., and Speece, R. E. 1967. The role of enzymes in the contact stabilization process. J. Wat. Poll. Cont. Fed., 38:(3)369.

1008. Siebert, C. L. 1940. A digest of industrial waste treatment. Penn. Dept. Hlth., 1-55.

1009. Siebert, C. L. 1941. Eachus dairies-milk waste treatment works-analytical survey of efficiency (high rate filter). Unpublished report, Penn. Dept. Hlth.

1010. Siebert, C. L. 1946. The effect of industrial wastes on sewage treatment. Sewage Wks. J., 18:97.

1011. Siebert, C. L. 1955. In plant control of dairy wastes. Discussion. Sewage ind. Wastes, 27:(1)59-60.

1012. Siebert, C. L. 1957. Pennsylvania milk waste treatment methods. Sewage ind. Wastes, 29:(9)1038-1041.

1013. Sierp, F. 1967. Trade and industrial waste waters, 3rd Edition. Springer Verlag, Berlin/Heidelberg, 1-736.

1014. Silvester, D. K. 1959. Some experiences in the disposal of milk wastes. J. Soc. Dairy Technol., 12:228-231.

1015. Simha, N. N. 1959. Dairy plant wastes-prevention and treatment. Indian Dairym., 11:(3)66-67, 69, and 71-72.

1016. Sladka, A. 1965. The biocenosis of a trickling filter. Chem. Abstr., 63:17,675.

1017. Smet, G. D. 1952. Some applications of hypochlorous acid in the treatment of waste waters. Bull. mens. Cent. belge Etude Docum. Eaux, (23)40-41.

1018. Smit, J. 1955. The dairy industry and its waste water. Off. Org. Koninkl. Ned. Zuivelb. F. N. Z., 47:(49)865-866.

1019. Smit, J. 1955. Pollution and the measurement of the degree of pollution. Extract from the report of the Dairy Waste Commission. Off. Org. Koninkl. Ned. Zuivelb. F. N. Z., 47:(49)879-881.

1020. Smit, J. 1955. The processing of industrial effluents, particularly that of the dairying industry. Soils and Fert., 18:(1)64.

1021. Smith, J. K. 1953. Sanitation problems in a suburban area-Jackson County, Missouri. Publ. Hlth. Rept., Wash., 68:1161-1166.

1022. Smith, R. L., and Agneberg, W. 1963. Preparation of wastes for biological filters. Publ. Wks., N. Y., 94:(10)170,172,174.

1023. Smith, R. L., and Lammer, L. 1964. Waste treatment plant designed for odor control. Publ. Wks., N. Y., 95:116-117.

1024. Soc. An. F. R. Laiterie Des Fermiers Reunis. 1958. Treatment of milk trade waste waters. Chem. Zbl., 129:11,399.

1025. Society of Chemical Industry. 1942. Reports of the progress of applied chemistry. Volume 27. London, 1-552.

1026. Society of Chemical Industry. 1968. Reports on the progress of applied chemistry. Volume 52, 1967, 1-864.

1027. Solomon, I., Copolovici, E. C., Sternhell, H. 1959. Variations in the biochemical consumption of oxygen produced by some organic and mineral substances. Chem. Abstr., 53:11,727.

1028. Soltoft, M. J. 1967. New method of predicting the biochemical oxygen demand of brewery waste. J. Inst. Brew., 73:393-405.

1029. Sorensen, S. M. 1953. Use of dairy wastes for spraying. Dansk. Mejeritid., 51:(2)34-37.

1030. South African Council for Scientific and Industrial Research. 1951. Sixth annual report, 1950-1951. Pretoria, South Africa, 1-80.

1031. South African Council for Scientific and Industrial Research. 1952. Seventh annual report, 1951-1952. Pretoria, South Africa, 1-122.

1032. South African Council for Scientific and Industrial Research. 1953. Eighth annual report, 1952-1953. Pretoria, South Africa, 1-166.

1033. South African Council for Scientific and Industrial Research. National Institute for Water Research. 1963. Report of the Director for 1961. Analysis. Council for Scientific and Industrial Research Spec. Rept. No. W20, 1-76.

1034. Southgate, B. A. 1948. Treatment of waste waters from agricultural industries. Report, 7th International Congress of Agricultural industries, Paris, Vol. I, Q3-A.

1035. Southgate, B. A. 1948. Treatment and disposal of industrial waste waters. H. M. Stationery Office, London, 1-336.

1036. Southgate, B. A. 1948. Treatment of milk washings by addition of coagulants, sedimentation, and biological filtration. Dairy Inds., 13:(3)235-240.

1037. Southgate, B. A. 1949. Treatment of waste waters from the dairy industry. 12th Int. Dairy Congr., 3:Sect. 3, 671-677.

1038. Southgate, B. A. 1950. Water pollution research. Brit. Sci. News, 3:(25)11-12.

1039. Southgate, B. A. 1952. Waste disposal in Britain. Ind. Eng Chem., 44:524.

1040. Southgate, B. A. 1954. Treatment and disposal of waste waters from dairies. Dairy Sci. Abstr., 16:427-442.

1041. Southgate, B. A., and Jenkins, S. H. 1947. Pollution by trade wastes from food industries. Nature, 160:200.

1042. Sparham, V. R. 1964. The behavior of sludge and slurries-the effects of compression. Effl. Wat. Treat. J., 5:25,27, and 29.

1043. Spaulding, R. A. 1948. The anaerobic digestion rates of milk wastes. Proc. 4th Ind. Waste Conf., Purdue Univ., 40-44.

1044. Spohn, H., and Fischer, W. K. 1967. Biologically hard and soft detergents in sewage purification plants. III. Chem. Abstr., 67:9,676.

1045. Sprague, G. W. 1954. What has happened to whey? Mfd. Milk Prod. J., 45:(11)26.

1046. Stanbridge, H. H. 1955. The development of biological filtration. Water and Sanitary Engineer, 5:252-255.

1047. Stander, G. J. 1951. Effluents from milk processing industries. II. Their treatment before disposal. S. Afr. Dairym., 13:52.

1048. Stander, G. J. 1952. The problem of dairy waste disposal. S. Afr. Dairym., 14:515-517.

1049. Stander, G. J. 1952. Problem of waste disposal in the dairy industry. Can. Dairy Ice Cream J., 31:(6)56,60-62,(7)48-49.

1050. Standeven, W. E. 1965. Milk plant waste disposal. 39th Ann. Rept., N. Y. State Assn. Milk and Food San., 111.

1051. Staniar, W. 1950. BOD of pure compounds. Plant Engineering Handbook, 1st Edition. McGraw Hill Publishing Company.

1052. Stanton, J. H., and Smith, G. A. 1967. Increasing CIP efficiency. Wyandotte Sanifacts, No. 2, 7-13.

1053. Stapf, R. J., and Carl, C. E. 1953. Solving industrial waste disposal problems in South Dakota. Publ. Wks., N. Y., 84:(8) 76-78 and 127-129.

1054. Steffen, A. J. 1948. Milk waste disposal, a discussion. Sewage Wks. J., 20:707-708.

1055. Steffen, A. J. 1957. Some recent developments in dairy waste research. Proc. 12th Ind. Waste Conf., Purdue Univ., 390-394.

1056. Steffen, A. J. 1959. Control of cleaning wastes in food industries. Chem. Eng. Progr., 55:(11)79-81.

1057. Stein, F. 1968. Controlling water pollution. Am. Dairy Rev., 30:18.

1058. Stenger, V. A. 1969. Rapid analysis for the organic carbon content and oxygen demand of waste water. 17th Ann. Dairy Eng. Conf., Michigan State Univ., 63-66.

1059. Stijmans, J. 1952. Pollution of water and treatment of waste waters in the dairy industry. Chem. Zbl., 123:3,552.

1060. Stinco, R. A. 1969. Treatment of dairy wastes. Ind. lechera, 51:(601/602)240-242.

1061. Stitt, E. R., Clough, P. W., and Clough, M. C. 1943. Practical bacteriology, haematology, and animal parasitology, 9th Edition. H. K. Lewis and Co., London, 1-976.

1062. Stouse, D. C. 1964. Waste stabilization ponds in Iowa--a survey. WatWks. Wastes Eng., 1:(8)52.

1063. Stoves, A. A. 1970. Extended aeration treatment of milk wastes. Ir. agric. Cream. Rev., 23:(2)15-17.

1064. Stoves, S. H. 1967. Use of extended aeration for the treatment of milk wastes. Munic. Eng., 144:1731-1732.

1065. Strell, M. 1939. The action of active chlorine on the principal constituents of milk and dairy wastes. Vom Wasser, 14:187-215.

1066. Strell, M. 1940. Contribution to the problem of the disposal and treatment of waste waters from dairies. Stadereinigung, 32:85.

1067. Strell, M. 1942. Ferric chloride as a coagulant in sewage treatment. Water. A year book for water chemistry and the technique of water treatment.

1068. Stringer, W. E. 1949. Whey once discarded now provide useful products. Fd. Inds., 21:892-895.

1069. Sturve, H. 1953. The present state of treatment of milk trade waste waters. Zbl. Bakt., I., Ref., 152:109.

1070. Struzeski, E. J., and Nemerow, N. L. 1957. Dispersed growth aeration of protein-glucose mixtures. Proc. 12th Ind. Waste Conf., Purdue Univ., 145-156.

1071. Stundl, K. 1949. The treatment of milk trade waste waters and the possibility of their utilization. 12th Int. Dairy Congr., 3:Sect. 3, 678-687.

1072. Stundl, K. 1951. The influence of various waste waters on the bacterial decomposition of nitrogen compounds. Hyg. Infektkr., 133:169-175.

1073. Stundl, K. 1952. Pollution of streams by milk industry waste waters and experiences with a process of treatment with coagulants. Ber. AbwassTechn. Verein, 3:153-157.

1074. Subcommittee on Dairy Waste, Dairy Industry Committee and National Technical Task Committee on Industrial Wastes. 1959. An industrial waste guide to the milk processing industry. Publ. Hlth. Serv. Publ. No. 298, 1-22.

1075. Subcommittee on Environmental Improvement. 1969. Cleaning our environment--the chemical basis for action. American Chemical Society, 1-249.

1076. Svoboda, M. 1955. Studies on the purification of dairy effluent by fermentation. Zpravy Vyzkumneho ustavu pro mleko a vejce, Praha, (3/4)17-22.

1077. Svoboda, M. 1956. Results of trials in 1955-1956 into the purification of dairy effluent. Zpravy Vyzkumneho ustavu pro mleko a vejce, Praha, (3/4)54-64.

1078. Svoboda, M. 1958. Conclusion of experiments on the purification of dairy effluent by the Pien method. Zpravy Vyzkumneho ustavu pro mleko a vejce, Praha, (2)72-82.

1079. Svoboda, M. 1960. Utilization of dairy effluent in agriculture. Zpravy Vyzkumneho ustavu mlekarenskeho, Praha, 8:(2)44-51.

1080. Svoboda, M. 1966. On the problem of terminology: Ponds, tanks, lagoons. Vodohospdarske TEI, 8:223.

1081. Svoboda, M. 1970. Composting of non-feedable whey and of sludge from effluent treatment plants. 18th Int. Dairy Congr., I - E, A. 1.2, 12.

1082. Svoboda, M., and Salplachta, J. 1956. Some observations on the purification of dairy effluent by *Geotrichum candidum*. Csl. Mikrobiol., 1:(4)176-182.

1083. Svoboda, M., and Salplachta, J. 1956. Treatment of dairy wastes by means of *Oospora lactis*. Chem. Abstr., 50:16,000.

1084. Svoboda, M., Saga, P., and Mnuk, M. 1968. Use of oxidation trenches for purifying effluent in Polish dairies. Prum. Potravin. 19:(4)208-211.

1085. Svoboda, M., Salplachta, J., Franlisek, T. 1960. Experiments with the Pien method for dairy waste waters purification. Prum. Potravin, 11:151-182.

1086. Svoboda, M., Salplachta, J., and Hlavka, M. 1961. Single-stage fermentation of dairy waste water. Vod. Hospid., 11:168.

1087. Svoboda, M., Gillar, J., Salplachta, J., and Hlavka, M. 1968. Economics of dairy effluent purification in Czechoslovakia. Prum. Potravin, 20:(6)182-186.

1088. Svoboda, M., Gillar, J., Salplachta, J., and Hlavka, M. 1970. Economy of dairy wastes disposal in Czechoslovakia dairy plants. 18th Int. Congr., I-E, A. 1.2, 16.

1089. Svoboda, M., Hlavka, M., Salplachta, J., and Stelcova, D. 1962. Study on the quantity and pollution of dairy effluent in Czechoslovakia. Sb. vys. Sk. Chem.-technol. Praze, Potravin Technol., 6:(2)139-168.

1090. Svoboda, M., Salplachta, J., Hlavka, M., and Stelcova, D. 1963. Further experiments with the single-stage fermentation of dairy effluent. Prum. Potravin, 14:(4)193-197.

1091. Svoboda, M., Salplachta, J., Hlavka, M., and Stelcova, D. 1964. The one step fermentation of waste waters as viewed from dairying practices. Chem. Abstr., 60:6,609.

1092. Svoboda, M., Salplachta, J., Hlavka, M., and Turcin, F. 1960. Single-stage fermentation of dairy effluent. Veda a Vyzkum v. Prumyslu Potravinarskem, 6:183-208.

1093. Svoboda, M., Gillar, J., Hlavka, M., Salplachta, J., and Stelcova, D. 1967. Single-stage fermentation of dairy effluent in new treatment plants. Prum. Potravin, 18:(7)342-351.

1094. Svoboda, M., Gillar, J., Salplachta, J., Hlavka, M., Stelcova, D. 1963. Final purification of dairy effluent in high trickling filter. Sb. Praci vyzk. Ust. Mlek, 130-149.

1095. Svoboda, M., Gillar, J., Salplachta, J., Hlavka, C. M., and Stelcova, D. 1966. Purification of dairy waste by means of biological tower filter plant. 17th Int. Dairy Congr., E/F:723-734.

1096. Svoboda, M., Gillar, J., Hlavak, M., Salplachta, J., Stelcova, D., and Marvan, P. 1966. Purification of dairy waste waters by means of lagoons. 17th Int. Dairy Congr., E/F715-722.

1097. Svoboda, M., Gillar, J., Salplachta, J., Hlavka, M., Stelcova, D., and Marvan, P. 1964. Secondary stage treatment of dairy waste water on deep trickling filter. Vod. Hospid., 14:219-222.

1098. Swaby, R. J. 1946. Production of lactic acid. I. From whey. Fd. Ind., 18:1636.

1099. Swanson, E., and Ziemba, J. V. 1967. Seek more profits from plant wastes. Fd. Eng., 39:110, 112, 114, 117.

1100. Swanwick, J. D., Bruce, A. M., and Vandyke, K. G. 1968. Pollution by synthetic detergents: towards a solution. Wat. Poll. Cont., London, 67:91-99.

1101. Swope, H. G., and Kenna, M. 1950. Effect of organic compounds on biochemical oxygen demand. Sewage ind. Wastes Eng., 21:467.

1102. Symons, J. M., and McKinney, R. E. 1958. The biochemistry of nitrogen in the synthesis of activated sludge. Sewage ind. Wastes, 30:(7)874.

1103. Szontag, J. 1962. A new method for determining oxygen demand of water with high content of organic matter. Tejipari Kutat. Közlem., 46-55.

1104. Technical Practice Committee, Subcommittee on Units of Expression. 1966. Units of expression for wastes and waste treatment-manual of practice no. 6. J. Wat. Poll. Cont. Fed., 38:451-458.

1105. Tewes, G. 1950. Utilization of milk trade waste waters in agriculture. Chem. Zbl., 121:II,2,959.

1106. Tewes, G. 1954. The disposal of dairy waste waters. Dte. Molk.-Zgt., 75:67-69.

1107. Tewes, G., and Gavel, L. 1953. The stimulation of the development of soil bacteria by dairy wastes and the changes of the soil caused by them. 3rd Int. Dairy Congr., 13:975-982.

1108. Thayer, P. M. 1951. Activated sludge treatment of milk wastes. Sewage ind. Wastes, 23:(12)1537-1539.

1109. Thayer, P. M. 1951. New design for an activated sludge plant to treat milk wastes. Proc. 6th Ind. Waste Conf., Purdue Univ., 171.

1110. Thayer, P. M. 1952. Design features of activated sludge plants for treating milk wastes. Proc. 7th Ind. Waste Conf., Purdue Univ., 509-517.

1111. Thayer, P. M. 1953. Milk waste treatment by activated sludge. Wat. Sewage Wks., 100:(1)34.

1112. Thom, R. 1959. Survey of important methods of dairy waste treatment. Chem. Abstr., 31:11,729.

1113. Thom, R. 1962. Treatment of dairy effluent by the activated sludge method. Zeszyt. nauk. Wyzsz. Szkol. roln. Olsztyn., 13:(3)369-385.

1114. Thom, R. 1966. Treatment of dairy waste waters by the activated sludge method with large bubble aeration. 17th Int. Dairy Congr., E/F:709-714.

1115. Thom, R. 1966. Determination of the pollution load in dairy waste water by the Eldridge dichromate method. 17th Int. Dairy Congr., E/F:781-784.

1116. Thom, R., and Glowacki, J. 1959. Study of the activated sludge process for the treatment of dairy effluent. Prace Inst. Przem. Mlecz., 6:(3)51-76.

1117. Thom, R., Glowacki, J., and Srzednicka, W. 1959. Purification of dairy wastes by the activated sludge method. Acta microbiol. polon., 8:(1/2)175-179.

1118. Thomas, S. B. 1949. The types of bacteria commonly found in farm and creamery water supplies and their action on milk and milk products. J. Soc. Dairy Technol., 2:2224-232.

1119. Thome, K. E., and Liljegrer, G. 1958. Determining whey expulsion from curd on a laboratory scale as a method for controlling the cheese-making ability of milk. Institute for Dairy Technology, Alnarp, Sweden, 1922-1927.

1120. Thompson, E. C. 1954. Report on activities of the Dairy Industry Committee on waste disposal. Proc. Milk Ind. Foundation, Plant Section.

1121. Thompson, F. N. 1945. Water supplies for milk plants and dairy farms. 19th Ann. Rept., N. Y. State Assn. Milk and Food San., 7.

1122. Toerien, D. F., and Hattingh, W. H. J. 1969. Review paper: Anaerobic digestion. I. The microbiology of anaerobic digestion. Wat. Res., 3:385-416.

1123. Tookos, I. 1965. Model experiments for the purification of dairy effluents by aeration. Elelm. Ipar, 19:(12)367-371.

1124. Trebler, H. A. 1939. Methods of disposing of dairy wastes. Manual Dairy Manuf. Conf., Univ. Illinois, 259-267.

1125. Trebler, H. A. 1941. The disposal of dairy wastes. J. Milk Technol., 4:93.

1126. Trebler, H. A. 1944. Waste savings by improvements in milk plant equipment. Proc. 1st Ind. Waste Conf., Purdue Univ., 1-190.

1127. Trebler, H. A. 1946. Research on milk wastes. Proc. 2nd Ind. Waste Conf., Purdue Univ., 125.

1128. Trebler, H. A. 1949. Private communication with Professor Mitten, Oct. 10, 1949.

1129. Trebler, H. A. 1953. Treatment of industrial wastes in municipal sewage plants. Proc. 2nd Sth. Munic. Ind. Waste Conf., 52.

1130. Trebler, H. A. 1954. Summary: Private versus public waste disposal. Proc. Milk Industry Foundation, Plant Section.

1131. Trebler, H. A. 1955. Discussion of milk industry report. Proc. 1954 Penn. State Chamber of Commerce.

1132. Trebler, H. A. 1956. 1955 industrial wastes forum. The dairy industry. Prevention of stream pollution by the treatment or elimination of wastes at their source. Sewage ind. Wastes, 28:(5)651-660.

1133. Trebler, H. A., and Harding, H. G. 1947. Dairy waste disposal. Chem. Eng. Prog., 43:(5)255.

1134. Trebler, H. A., and Harding, H. G. 1947. Dairy industry. Ind. Eng. Chem., 39:608.

1135. Trebler, H. A., and Harding, H. G. 1948. Two-stage high-rate trickling filters for dairy-waste treatment. Proc. 4th Ind. Waste Conf., Purdue Univ., 9-14.

1136. Trebler, H. A., and Harding, H. G. 1948. Milk waste problem, review. Sewage ind. Wastes, 20:(3)594.

1137. Trebler, H. A., and Harding, H. G. 1949. United States trends in disposal of dairy waste waters. 12th Int. Dairy Congr., 3:Sect. 3, 688-697.

1138. Trebler, H. A., and Harding, H. G. 1955. Fundamentals of the control and treatment of dairy waste. Sewage ind. Wastes, 27:1369-1382.

1139. Trebler, H. A., and Harding, H. G. 1955. Experience and questions concerning aeration methods as applied to dairy wastes. Proc. 10th Ind. Waste Conf., Purdue Univ., 1-16.

1140. Trebler, H. A., and Horton, J. P. 1956. Combination settling, flow division and weir tank for waste disposal systems. J. Dairy Sci., 39:A73.

1141. Trebler, H. A., Ernsberger, R. P., Roland, C. J. 1938. Dairy waste elimination and sewage disposal. Sewage Wks. J., 10 (1938) 868-887.

1142. Tregubov, V. 1940. On methods of purifying the waste waters from dairies and cheese factories. Chem. Zbl., 1:3001.

1143. Tregubov, V. 1953. Waste waters from butter factories. Chem. Abstr., 47:10,757.

1144. Treiber, H., Bederke, G., and Falk, B. 1957. A continuous thermochemical method for the purification of dairy effluent. Molk.-u.Käs.-Ztg., 8:(5)124-128.

1145. Trenda, O. 1967. Automation of a plant for treating dairy effluent. Prum. Potravin, 18:(7)339-341.

1146. Triggs, W. W., and Dorr Company, Inc. 1945. Purification of liquids. British Patent 570,078.

1147. Troemper, A. P. 1951. By-product recovery features Illinois waste progress. Wastes Eng., 22:534-543.

1148. Truesdale, G. A., and Mann, H. T. 1968. Synthetic detergents and septic tanks. Survr. munic. Cty. Engr., 131:(3953)28-30 and 33.

1149. Tsvei, V. 1969. Automation of dairy waste disposal. Moloch. Prom., 30:(3)37-39.

1150. Tucker, L. O. 1956. One per cent of the milk is wasted down the sewer. Wastes Eng., 27:325-326.

1151. Uber, W. J., and Rogers, H. G. 1951. Dairy and food processing wastes predominate in Minnesota. Wastes Eng., 22:538-540.

1152. Uhlmann, P. A. 1944. Charges to industries for treating their wastes in a municipal plant. Publ. Wks., N. Y., 75:(12)23.

1153. Union of Soviet Socialist Republics, Ministry of Public Economy. 1965. The purification of waste waters containing synthetic surface-active substances. Nauch. Trudy Akad. Kommun. khoz., 37:1-144.

1154. United States Department of Agriculture. 1952. Fermentation process yields B_{12} supplement. Chem. Eng. News, 30:338.

1155. United States Federation of Sewage and Industrial Waste Associations, Committee on Research, Section A. 1951. A critical review of the literature of 1950 on sewage, waste treatment, and water pollution. Sewage ind. Wastes, 23:555-642.

1156. United States Federation of Sewage and Industrial Wastes Associations, Committee on Research, Section A. 1952. A critical review of the literature of 1951 on sewage, waste treatment, and water pollution. Sewage ind. Wastes, 24:541-641.

1157. United States Federation of Sewage and Industrial Wastes Associations, Committee on Research, Section A. 1953. A critical review of the literature of 1952 on sewage, waste treatment, and water pollution. Sewage ind. Wastes, 25:511-547 and 633-683.

1158. United States Federation of Sewage and Industrial Wastes Associations. 1954. A critical review of the literature of 1953 on sewage, waste treatment, and water pollution. Sewage ind. Wastes, 26:573-615 and 695-744.

1159. United States Federation of Sewage and Industrial Wastes Associations. 1955. A critical review of the literature of 1954 on sewage, waste treatment, and water pollution. Sewage ind. Wastes, 27:515-571 and 633-688.

1160. United States Federation of Sewage and Industrial Wastes Associations. 1956. A critical review of the literature of 1955 on sewage, waste treatment, and water pollution. Sewage Ind. Wastes, 28:595-636 and 707-764.

1161. United States Federation of Sewage and Industrial Wastes Associations. 1957. A review of the literature of 1956 on sewage, waste treatment, and water pollution. Sewage Ind. Wastes, 29:497-523, 613-653, and 727-756.

1162. United States Federation of Sewage and Industrial Wastes Associations. 1958. A review of the literature of 1956 on sewage, waste treatment and water pollution. Sewage Ind. Wastes, 30:601-633, 717-756, and 839-873.

1163. United States Federation of Sewage and Industrial Wastes Associations. 1959. A review of the literature of 1958 on sewage, waste treatment and water pollution. Sewage ind. Wastes, 31:501-541, 615-661, and 763-803.

1164. United States Public Health Service. 1942. Industrial waste guides. Final report to the Ohio River Committee, 1-328.

1165. United States Public Health Service. 1942. Treatment of industrial wastes. Public Works, 73:(11)25.

1166. United States Public Health Service. 1959. An industrial waste guide to the milk processing industry. U. S. Public Health Service Publ. No. 298.

1167. United States Water Pollution Control Federation. 1960. A review of the literature of 1959 on waste water and water pollution control. J. Wat. Poll. Cont. Fed., 32:443-481, 545-593, and 681-720.

1168. United States Water Pollution Control Federation. 1961. A review of the literature of 1960 on waste water and water pollution control. J. Wat. Poll. Cont. Fed., 33:445-476, 549-584, and 681-710.

1169. United States Water Pollution Control Federation. 1962. A review of the literature of 1961 on waste water and water pollution control. J. Wat. Poll. Cont. Fed., 34:419-458, 525-564, and 629-703.

1170. United States Water Pollution Control Federation. [illegible] A review of the literature of 1962 on waste water and water pollution control. J. Wat. Poll. Cont. Fed., 35:553-586, 687-727 and 819-876.

1171. United States Water Pollution Control Federation. 1964. A review of the literature of 1963 on waste water and water pollution control. J. Wat. Poll. Cont. Fed., 36:535-572, 659-711, and 791-863.

1172. United States Water Pollution Control Federation. 1965. A review of the literature of 1964 on waste water and water pollution control. J. Wat. Poll. Cont. Fed., 37:587-646, 735-799, and 887-979.

1173. United States Water Pollution Control Federation. 1966. A review of the literature of 1965 on waste water and water pollution control. J. Wat. Poll. Cont. Fed., 38:872-874.

1174. United States Water Pollution Control Federation. 1967. A review of the literature of 1966 on waste water and water pollution control. J. Wat. Poll. Cont. Fed., 39:868-872.

1175. United States Water Pollution Control Federation. 1968. A review of the literature of 1967 on waste water and water pollution control. J. Wat. Poll. Cont. Fed., 40:1145-1150.

1176. United States Water Pollution Control Federation. 1969. A review of the literature of 1968 on waste water and water pollution control. J. Wat. Poll. Cont. Fed., 41:1164-1169.

1177. Urbain, O. M., and Stemen, W. R. 1941. Magnetic flocculation for removing suspended matter from whey, distillery and yeast plant wastes, straw board mill wastes, etc. Chem. Abstr., 35:3,376.

1178. Vaillant, C. M. E. 1942. Purification of dairy waste waters and similar waste waters. Chem. Zbl., 2:2,071.

1179. Varna, M. M., and Hall, L. H. 1966. BOD of pure carbohydrates and its relation to the chemical structure. Wat. Sewage Wks., 113:102-109.

1180. Vaseen, V. A. 1957. Quasi-municipal plant biofilters sewage with meat and dairy wastes. Wastes Eng., 28:633 and 640.

1181. Veale, P. O. 1941. Dairy factory drainage. Rept. Dept. Sci. Ind. Res., N. Z., 10.

1182. Veale, P. O. 1942. The volume and composition of dairy factory drainage in Taranaki. N. Z. J. Sci. Technol., 23:(3a),166a-180a.

1183. Veale, P. O. 1946. The effect of dairy factory drainage upon the quality of streams in Taranaki. N. Z. J. Sci. Technol., 27:Sect. B, (4)282-301.

1184. Vennes, J. W., and Olson, O. O. 1967. BOD and bacterial changes in various wastes during BOD testing. Off. Bull. N. Dak. Wat. Sewage Wks. Conf., 34:(7 and 8)2-5.

1185. Vermont Department of Water Resources. 1967. Results of whey research projects, 1958-1962.

1186. Viehl, K. 1941. The effect of the content of oxygen on the biochemical oxygen demand and on the natural self-purification of water as well as on the activated sludge process. Zbl. Bakt., II, 103:245.

1187. Viehl, K. 1949. The changes in nitrogen caused by biological treatment of sewage and by sludge digestion. Gesundheitsingenieur, 70:365-370.

1188. Viehl, K. 1960. Treatment of waste waters from rural industries. Ber. AbwassTechn. Verein., 11:341-353.

1189. Viehl, K. 1960. Sewage oxidation pond at Grossdungen. Chem. Abstr., 54:20,027.

1190. Viehl, K. 1961. The waste water problem in dairy plants. Molk.-u.Käs.-Ztg., 12:369.

1191. Viehl, K. 1963. Purification of waste water from dairy plants. Molk.-u.Käs.-Ztg., 14:1,579.

1192. Viehl, K., Murdach, K., and Neamann, H. 1963. Experiences with activated sludge-oxidation ditches in Lower Saxony. Gesundheitsingenieur, 84:(9)261.

1193. Voege, F. A., and Stanley, D. R. 1963. Industrial waste stabilization ponds in Canada. J. Wat. Poll. Cont. Fed., 35:(8)1019-1024.

1194. Vogl, K., Schumann, G., and Peters, G. 1966. Rapid determination of biological oxygen demand (BOD) in brewery effluents. J. Sci. Fd. Agric., Abstr., 17:325.

1195. Vogle, G. 1964. Purification of waste water. Mejeriposten, 53:833.

1196. Vosters, T. A. J. 1955. The administrative side of the problem of the purification of waste water. Off. Org. Koninkl. Ned. Zuivelb. F. N. Z., 47:(49)873-877.

1197. Vrignaud, Y. 1965. Purification of effluent from cheese factories. The Fromageries Bel process. Publ. Hlth. Eng. Abstr., 45:313.

1198. Wakefield, J. W. 1953. As Florida grows-so does its industrial wastes problems. Wastes Eng., 24:495-497.

1199. Walker, C. L. 1923. Studies on the treatment and the disposal of dairy wastes. Cornell Univ., Agr. Exp. Sta., 1-188.

1200. Wallace, W. S., and MacKenzie, R. D. 1947. An outbreak of paratyphoid B. fever at Wootton, Isle of Wright. Bull, Hyg., Lond., 22:315.

1201. Wallgren, K. Leesment, H., and Magnusson, F. 1967. Investigations on irrigation with dairy waste water. Meddn. svenska Mejeriern. Riksforen., 85:20.

1202. Walzholz, G. 1970. Studies on technical aspects of dairy waste treatment in a dairy. J. Molkereizeitung, Hild., 14:(20)651-654.

1203. Walzholz, G. 1961. Treatment of dairy sewage. Publ. Hlth. Eng. Abstr., 41:(12)33.

1204. Walzholz, G. 1964. Disposal and treatment of dairy waste waters. Int. Dairy Fed. Ann. Bull., (2)1-57.

1205. Walzholz, G. 1966. Waste control in the dairy plant. 17th Int. Dairy Congr., E/F:785-792.

1206. Walzholz, G. 1967. Dairy effluent. Dte. Molk. Ztg., 88:(42) 1722-1724, (43)1778, (44)1811, (45)1849-1850, (46)1888-1889, (47)1926-1927, (48)1960-1962.

1207. Walzholz, G., and Pester, A. 1960. Engineering problems in the collection and evaluation of dairy effluent. Dte. Molk.-Ztg., 81:(51/52)1886-1889.

1208. Walzholz, G., Gronau, J., and Koster, H. 1967. The effect of sanitary measures on the quantity of dairy effluent and its pollution. Kieler milchw. ForschBer., 18:(4)235-247.

1209. Walzholz, G., Pester, A., Lembke, A., and Schmidt, G. 1959. The treatment of dairy effluents with Aquapura experimental plant in Loccum. Dairy Sci. Abstr., 21:248.

1210. Walzholz, G., Quest, H., Lembke, A., and Fehlhaber, H. J. 1959. Treatment of dairy effluent with Aero-Accelator. Dte. Molk.-Ztg., 80:(14)482-485.

1211. Walzholz, G., Quest, H., Lembke, A., and Fehlhaber, H. J. 1959. Treatment of dairy effluent by the Ferrobion-percolating method. J. Molkereizeitung, Hild., 13:(14)395-398.

1212. Walzholz, G., Lembke, A., Gronau, J., Koster, H., and Schmidt, H. 1968. Effluent problems in dairy factories. Kieler milchw. ForschBer., 20:(5)415-532.

1213. Warrick, L. F. 1940. New developments in treatment of milk wastes. Fd. Inds., 12:(9)46-48 and 99.

1214. Warrick, L. F., and Wisniewski, T. F. 1946. Water and sewage problems as related to milk sanitation. J. Milk Technol., 9:(4)214.

1215. Washington, D. R., and Symons, J. M. 1962. Volatile sludge accumulation in activated sludge systems. J. Wat. Poll. Cont. Fed., 34:(8)767-790.

1216. Washington State Pollution Control Commission. 1950. Minimum requirements for the control of industrial wastes. Sewage ind. Wastes, 22:514-520.

1217. Wasserman, A. E. 1960. The rapid conversion of whey to yeast. Dairy Eng., 77:374.

1218. Wasserman, A..E., and Porges, N. 1959. Whey utilization: Summary of laboratory investigations in yeast propagation. Proc. 14th Ind. Waste Conf., Purdue Univ., 535-546.

1219. Wasserman, A. E., Hampson, J. W., and Alvare, N. F. 1961. Large-scale production of yeast in whey. J. Wat. Poll. Cont. Fed., 33:1090-1094.

1220. Wasserman, A. E., Hopkins, W., and Porges, N. 1958. Whey utilization-growth conditions for *Saccharomyces fragilis*. Sewage ind. Wastes, 30:913-920.

1221. Wasserman, A., Hopkins, W., and Porges, N. 1959. Rapid conversion of whey to yeast. 15th Int. Dairy Conf., 2:1241-1247.

1222. Waterfall, C. E. 1965. Trade waste disposal agreements in a rural area. Publ. Hlth. Eng. Abstr., 45:967.

1223. Water Pollution Control Federation. 1952. Manual of practice no. 5: Air diffusion in sewage works. Washington, D.C.

1224. Water Pollution Control Federation. 1959. Manual of practice no. 8: Sewage treatment plant design. Washington, D.C.

1225. Water Pollution Control Federation. 1966. Manual of practice no. 11: Operation of waste water treatment plants. Washington, D.C.

1226. Water Pollution Control Federation. 1968. Proceedings of the 3rd international conference on pollution research. Munich, Germany.

1227. Watson, C. W., Jr. 1955. In-plant control of dairy wastes. Sewage ind. Wastes, 27:(1)55-60.

1228. Watson, C. W., Jr. 1960. Practical aspects od dairy waste treatment. Proc. 15th Ind. Waste Conf., Purdue Univ., 81-89.

1229. Watson, C. W., Jr. 1962. Automation and pollution control. 10th Ann. Dairy Eng. Conf., Michigan State Univ., 74-80.

1230. Wattie, E. 1942. Cultural characteristics of zoogloea-forming bacteria isolated from activated sludge and trickling filters. Publ. Hlth. Rept., Wash., 57:1519.

1231. Webster, L. F. 1968. Hydrocyclone saves water, helps waste treatment. Wat. Poll. Cont., Ont., 106:(1)37-38.

1232. Welch, F. M. 1968. Preliminary results of a new approach in the aerobic biological treatment of highly concentrated wastes. Proc. 23rd Ind. Waste Conf., Purdue Univ.

1233. Wells, N. and Whitton, J. S. 1966. The influence of dairy effluents on soil and plant composition. N. Z. J. Agric. Res. 9(3) 565-575.

1234. Werner, H. 1969. Purification of dairy waste in an activated-sludge plant at the Rue co-operative dairy. Beretn. St. Forso-Ksmejeri, 173:1-22.

1235. Werner, H. 1970. Whey as an effluent problem. Maelkeritidende, 83:(19)431-438.

1236. Werner, H., and Lytken, E. K. 1968. Review of cases involving dairy effluent for the period October, 1967-October, 1968. Bilag til 28. arsberetning, 47-54.

1237. Weston, R. F. 1953. Industrial water pollution abatement. Chem. Eng. News, 31:(2).

1238. Wheatland, A. B. 1960. Treatment of waste waters from milk products factories. Waste Treatment, Pergamon Press, 411-428.

1239. Wheatland, A. B. 1967. Activated-sludge treatment of some organic wastes. Proc. 22 Ind. Waste Conf., Purdue Univ., 983-1008.

1240. Wheatland, A. B. 1967. The treatment of effluents from the milk industry. Chemy Ind., 37:1547-1551.

1241. Wheatland, A. B., and Barne, J. B. 1964. Treatment of farm effluents. Chemy Ind., 34:357.

1242. White, J. C. 1960. Disposing of dairy wastes. Am. Milk Rev., 22:(12)38.

1243. White, J. C. 1967. Approaches to controlling food plant waste. Am. Dairy Rev., 29:(10)46, 102-103.

1244. Whitehead, D. 1968. Fundamentals of mechanical recirculating cleaning. I. High pressure low-volume cleaning. II. Recirculation cleaning. 55th Annual Meeting of International Association of Milk, Food, Environmental Sanitarians.

1245. Whittier, W. O., and Webb, B. H. 1950. By-products from milk. New York: Reinhold Publishing Company, p. 33.

1246. Wierzbicki, E. 1957. Purification of dairy waste waters. Przegl. mlecz., 5:(4)11.

1247. Wieselberger, F. 1960. The treatment of milk trade waste waters by alternating double filtration. Ber. AbwassTechn. Verein., 11:264-274.

1248. Wilcox, H. V. 1948. Technical Bulletin No. 962, United States Department of Agriculture.

1249. Wilson, J. N. 1953. How sanitary biologists contribute to waste treatment processes. Wat. Sewage Wks., 100:502-504.

1250. Wilson, M. A. 1946. High rate filters treat creamery wastes. Sewage Wks. Eng., 17:309.

1251. Windridge, M. E. 1941. Some views and experiences on the treatment of trade wates. Paper read at a meeting of the Institute of Sewage Purification.

1252. Winkler, S., and Thaler, S. 1958. The suitability of water treated by the Catadyn process in the Emmenthal cheese factory. Chem. Zbl., 128:11,976.

1253. Wisely, W. H. 1946. Treatment of sewage containing milk and brewery wastes at Highland, Illinois. Sewage Wks. J., 8:(4)624.

1254. Wisniewski, T. F. 1948. The chemistry and biology of milk waste disposal. J. Milk Fd. Technol., 11:293-300.

1255. Wisniewski, T. F. 1952. The chemistry and biology of milk waste disposal. Butter, Fat, and Solids, 11:(2)113-117.

1256. Wisniewski, T. F. 1954. How to handle a variety of waste-treatment problems. Chem. Abstr., 48:11,688.

1257. Wisniewski, T. F. 1961. Irrigation disposal of industrial wastes. Publ. Wks., N. Y., 92:(7)96.

1258. Wisniewski, T. F. 1965. What's being done in Wisconsin about dairy waste disposal? Mfd. Milk Prod. J., 56:(5)6 and 8.

1259. Wisniewski, T. F., and Muegge, O. J. 1951. Wisconsin's stream pollution control program. Wastes Eng., 22:540-543.

1260. Wittmann, J. 1953. Operation of a purification plant for dairy wastes. Molkereizeitung, 7:(3).

1261. Wittmer, E. F. 1940. Effect of milk waste on sewage treatment at Marysville, Ohio. Rept. Ohio Conf. Sewage Treatment, 75-82.

1262. Wittmer, E. F. 1941. Treating milk wastes by two stage filtration. Publ. Wks., N. Y., 72:(3)19-20, 37-38.

1263. Wittmer, E. F. 1948. Alternating two-stage filtration of sewage and milk waste. Sewage Wks. J., 20:846-848.

1264. Wix, P., and Woodbine, M. 1958. The disposal and utilization of whey. Dairy Sci. Abstr., 20:538-547, 622-634.

1265. Wix, P., and Woodbine, M. 1959. Mycological synthesis of fat from whey. I. Preliminary studies with stationary cultures. J. appl. Bact., 22:14-22.

1266. Wix, P., and Woodbine, M. 1959. Mycological synthesis of fat from whey. II. Comparative studies with shaken and stationary cultures using selected molds. J. appl. Bact., 22:175-183.

1267. Wolfner, W. J. 1964. Determination of biochemical oxygen demand using dichromate oxidation. J. Inst. Brew., 70:446-448.

1268. Woods, C. 1965. Determination of proteins in waste water. Proc. 20th Ind. Waste Conf., Purdue Univ., 501-515.

1269. Woods, C., and Malina, J. F. 1964. Glycine uptake by anaerobic waste-water sludge. Proc. 19th Ind. Waste Conf., Purdue Univ., 1011-1024.

1270. Woodward, R. L. 1962. Pollution caused by food and paper wastes. J. Am. Wat. Wks. Assn., 54:291-293.

1271. Woolery, R. G. 1969. Water and waste treatment. United States Patent 3,224,965.

1272. Woolings, N. D. 1952. Treatment of milk waste. Munic. Util., 90:(11)50, 52, 54, (12)25-28, 30, 32, and 44-45.

1273. Woolings, N. D. 1955. Milk waste disposal. I. An outline of the problem in Ontario including information on the sources and character of milk wastes. II. A discussion of the principal methods of milk waste disposal based upon laboratory and plant scale investigations. Can. Dairy Ice Cream J., 34:(5)27-29 and 60, (6)27-29, 40 and 42.

1274. World Health Organization, and Food and Agriculture Organization. 1960. Joint FAO/WHO expert committee on milk hygiene. Second Report. WHO Tech. Rept. Ser. No. 197, 1-56.

1275. Worseck, M. 1957. Production of certified milk obtained from cows fed with forage from sewage-irrigated fields near Berlin. Milchwissenschaft, 12:(11)438-439.

1276. Woste, H., and Nehrkorn, A. 1961. Experiments and observations in an oxidation channel for milk trade waste waters. Wass. u. Boden, 13:316.

1277. Wright, S. L. 1950. Fundamentals of trade effluent control. Sewage Purif., Part 2:85-89.

1278. Wuhrmann, K. 1956. Factors affecting efficiency and solids production in the activated sludge process. Biological Treatment of Sewage and Industrial Wastes, Vol. I.

1279. Wurtz, A. 1957. Fungi, bacteria, and algae in polluted waters. Bull. mens. Cent. belge Etude Document. Eaux, Nos. 78-79, 302-304.

1280. Wyeth Laboratories. 1962. Wyeth uses electrodialysis to desalt whey. Chem. Engng. News, 40:(41)44-45.

1281. Yerex, D. K. 1970. A factory's problem proves a farmer's benefit. N. Z. Dairy Exptr., 35:(9)29-32.

1282. Yoney, Z. 1964. By-products of Turkish milk industry and possibilities of their utilization. Chem. Abstr., 60:6,135.

1283. Young, J. C., and McCarty, P. L. 1967. The Anaerobic Filter for Waste Treatment. 23rd Ind. Waste. Conf., Purdue Univ.

1284. Yunis, S. M. 1967. Wet oxidation. Diss. Abstr., 27:B, 3976-3977.

1285. Zabierzewski, C. 1963. Technical progress in dairy effluent treatment. Przegel. mlecz., 11:(2)27-29, (4)15-20.

1286. Zack, S. I. 1953. Treatment and disposal of milk wastes. Sewage ind. Wastes, 25:177-187.

1287. Zack, S. I. 1956. Trickling filter treatment of wastes at two milk processing plants. Sewage ind. Wastes, 28:1009-1019.

1288. Zahradka, V. 1965. Contribution to the theory of the activated sludge process (Czech. Manuscript Trans. by Hana Havrankova), Proka, 1-94.

1289. Zall, R. R. 1968. Monitoring waste discharge: a new tool for plant management. Dissertation, Cornell University.

1290. Zall, R. R., and Jordon, W. K. 1969. Monitoring milk plant waste effluent-a new tool for plant management. J. Milk Fd. Technol., 32:(6)197-202.

1291. Zelinka, M. 1961. Effect of dairy and starch production effluents in the town of Pelhrimov on seed germination. Vlastiv. Sborn. Vysociny, 5:87-92.

1292. Zschaler. 1969. Effluent problems in dairy plants. Dte. Milchw. (Molk-u. Käs.-Ztg.), 47:1947.

1293. Zunker, F. 1957. Agricultural utilization of industrial waste waters. Zbl. Bakt., I., Ref., 164:168-169.

ADDENDUM TO REFERENCES CITED

9a. Aiba, S., Humphery, A. E., and Millis, Nancy F. 1965. Biochemical Engineering, Academic Press, New York.

9b. Aiba, S. and Toda, K. 1963. The effect of surfactant surface active agents on oxygen absorption in bubble aeration. I. J. Gen. Appl. Microbiol. 7:443.

9c. Agardy, F. J., Cole, R. D. and Pearson, E. A. 1965. Kinetic and activity parameters of anaerobic fermentation systems. Sanitary Engineering Research Laboratory Report 63-2 University of California, Berkeley, California.

9c. Albertsson, J. G., McWhirter, J. R., Robinson, E. K. and Vahldieck, M. P. 1970. Investigation of the use of high purity oxygen aeration in conventional activated sludge process. Water Pollution Control Research Series 17050 DNW 05/70 U. S. Department of Interior. Federal Water Quality Administration.

11a. Amado, M. A. 1964. Analysis of BOD reduction in trickling filters. M. S. Thesis. Cornell University.

14a. Ames, W. F., Behn, V. C. and Collings, W. Z. 1962. Transient operation of the trickling filter. Proc. ASCE, 88(SA3).

17a. Amramy, A., 1960. Stabilization ponds in Israel. Tavruah 8-9, 33.

25a. Andrews, J. F. 1968. A discussion of anaerobic treatment of soluble wastes - by McCarty, P. L. (670c). In Gloyna, E. F. and Eckenfelder, W. W. Jr. (402a) Adv. In Water Quality Improvement.

25b. Andrews, J. F., Cole, R. D., and Pearson, E. A. 1964. Kinetics and characteristics of multi-stage methane fermentation. Sanitary Engineering Research Laboratory Report No. 64-11, University of California, Berkley, California.

120a. Antonie, Ronald L. 1970. Response of the "bio-disc" process to fluctuating waste water flows. Paper presented at 25th Purdue Industrial Waste Conference, May 5-7, 1970.

124a. Arcievala, S. J. 1963. Proceedings of Symposium on Waste Treatment by Oxidation Ponds, Nagpur, India, Central Public Health Engineering Research Institute.

128a. Askew, M. W. 1970. Report at the Society of Dairy Technology, London, October 26 - as reported in Dairy Industries, Dec. 1970.

128a. Atkinson, B. A., Busch, A. W. and Dawkins, G. S. 1963. Recirculation reaction kinetics and effluent quality in a trickling filter flow model. J. Water Poll. Cont. Fed., 35, 10.

151a. Baumann, E. R. 1960. Waste treatment, C. G. Issac, Editor. Pergamon Press, Oxford.

154b. Behn, V. C. and Monadjeni, T. 1968. Developments in biological filtraction in Advances in Water Qaulity Improvement No. 1 Edited by Gloyna, E. F. and Eckenfelder, W. W. Jr.

189a. Boyle, W. C., Crabtree, K., Iaccarino, E. P., Lightfoot, E. N., Rohlich, G. A. 1968. Flocculation phenomena in biological systems. In Gloyna, E. F. and Eckenfelder, W. W. Jr. Adv. in Water Quality Improvement (402a)

189b. Bowles, J. T. 1911. Septic treatment of creamery sewage. Eng. record, 64:419-420.

198a. Buswell, A. M. In Undukofter, L. A. and Hickey, R. J. Ed. 1954. Industrial Fermentation, Chemical Pub. Co. N. Y. p. 518-555.

198a. Buswell. A. M., Boruf, C. J., Wiezman, C. K. 1932. Anaerobic stabilization of milk waste. Ind. Eng. Chem. 24:1423-25.

199a. California State Water Resources Control Board: 1968 Cannery waste treatment, utilization and disposal. Publication 39.

213a. Carver, C. E. Jr. 1955. Absorption of oxygen in bubble aeration. In biological Treatment of Sewage and Industrial Waste., Eckenfelder, W. W. and McCable, J. I. 149 Reinhold, N. Y.

225a. Chesters, G. 1959. Soil aggregation and organic matter decomposition. Wisconsin: pH. D. Thesis (After Sharratt et al. (898a)

251a. Coulter, J. N., Soneda, S., and Ettinger, M. B. 1957. Anaerobic contact process for sewage waste disposal. Sewage and Industrial Waste 29, 4, 468.

268a. Daub, H. 1957. Vergleich verschiedener Verfahren zur and behandlung von molkereiabwasser Vasser and Nahrung 2:23.

311a. Eckenfelder, W. W. 1958. Study of fruit and vegetable processing waste disposal methods in the Eastern region, final report, New York Canners Association.

311b. Eckenfelder, W. W. 1963. Designing for oxygen transfer. Wastes Engineering, Pages 80-83.

311c. Eckenfelder, W. W. 1961. Trickling filtration design and performance. Sanit. Eng. Div., Proc., ASCE 87 No. a4, July, 1961.

312a. Eckenfelder, W. W. Jr. 1966. Industrial Water Pollution Control, McGraw-Hill, N. Y. 275 pp.

312b. Eckenfelder, W. W. Jr. 1966. Mathematical relationships for bio-oxidation design. Civil Engineering Seminar, University of Washington, October 26, 1966.

314a. Eckenfelder, W. W. Jr., and Barnhart, E. L. 1961. The effect of organic substances on the transfer of oxygen from air bubbles in water. A. I. Ch. E. J. 7:631.

314b. Eckenfelder, W. W. Jr., and Ford, D. L. 1968. New concepts in oxygen transfer and aeration. In Advances in Water Quality Improvement. Vol. I. Gloyna, E. F. and Eckenfelder, W. W. Jr., Editors (402a).

314c. Eckenfelder, W. W., Barnhart, E. L. 1963. J. Water Pollution Control Fed. 35:12.

314d. Eckenfelder, W. W. Jr. 1961. Proceedings of the 16th Industrial Waste Conference, Extension Series No. 109, 115-125 Purdue University, Lawfayette, Indiana, 1961.

328a. Eldridge, E. F. The treatment of red beet, tomato, and squash cannery wastes. Bulletin 83, Michigan State College Engineering Experiment Station, p. 15, 1939, and Sewage and Industrial Wastes, 10:5, 914, Sept. 1938; 11, 4, 716; July 1939.

347a. Ethyl Corporation Commercial Development Division. 1968. Plot of percent BOD removal versus load in pounds BOD/1000 cu. ft., day, May 5, 1967, Revised May 13, 1968.

349a. Fair, G. M. and Geyer, J. C. 1955. Elements of water supply and waste water disposal. New York: John Wiley & Sons.

351a. Fair, G. M. and Thomas, H. A. Jr. 1950. The concept of interface and loading in submerged, aerobic, biological sewage treatment systems. Proceedings Institute Sewage Purification Part III.

360a. Fischer, G. 1956. Medicinsk-hygieniska nedicinsk-hygieniska synpunkterta avloppsfragor-Avloppstenik, Sv. kommunal-Tekn. Foreningen sid. 23.

362a. Fisher, C. P., Dryman, W. R. and Van Fleet, G. L. 1968. Waste Stabilization Procedures in Canada in Gloyna and Eckenfelder (402a).

374a. Fritz, S. 1957. Solar energy on clear and cloudy days, Scientific Monthly 84:55 in Fain et al (350).

380a. Funke, J. W. 1970. Industrial water and effluent management in the milk processing industry, CSIR dyed K-12. Published by the National Institute for Waste Research. Council for Scientific and Industrial Research, Pretoria, South Africa.

382a. Gaden, E. L. Jr. 1956. Aeration and oxygen transport in biological systems - basic considerations. In McCabe and Eckenfelder (669a).

382b. Galler, W. S. and Gotaas, H. B. 1964. Analysis of biological filter variables. Proc. ASCE, 90(SA6).

384b. Gates, W. E., Smith, J. H., Lin, S. and Ris, C. H. 1965. An anaerobicaerobic process for industrial waste water treatment. 1. The anaerobic process. Paper presented at the National Meeting of the Water Pollution Control Federation. Atlantic City, N. J.

400a. Gleason, G. H. and Loonam, A. C. 1934. Results of six months operation of chemical sewage purification. Sew. Works J. 6:450.

402a. Gloyna, E. F. and Eckenfelder, W. W., Jr. 1960. Advances in Water Quality Improvement No. 1. Univ. of Texas, Austin.

402b. Gloyna, Basis for waste stabilization pond desings in Gloyna, E. F. and Eckenfelder, W. W., Jr. Advances in Water Quality Improvement, Vol. 1. (402a).

408a. Gram, A. L. 1956. Reaction kinetics of aerobic biological processes. Sanitary Engineering Research Lab., No. 2. IER Series 90. Berkley: University of California (according to Pearsons, E. A. Kinetics of biological treatment. In Gloyna and Eckenfelder (402a)).

408b. Grantham, G. R. 1951. Trickling filter performance at intermediate loading rates. Sewage Ind. Wastes 23, 10, 1337.

408c. Grantham, G. R., Phelps, E. B., Calaway, W. T. and Emerson, D. L., Jr. 1950. Progress report on trickling filter studies. Sewage Ind. Wastes 23, 10, 867.

423a. Hagen, R. M., Haise, H. R. and Edminster, T. W. Ed. 1967. Irrigation of agricultural lands. Am. Soc. of Agronomy Monograph No. 11, Madison, Wisconsin.

448a. Herman, E. R., and Gloyna, E. F. 1958. Waste stabilization ponds III formulation of design equations. J. Water Pollin. Control Fed. 30:963.

455a. Heukelikian, H. and Weisberg, E. 1956. Bound water and activated sludge bulking. Sew. and Ind. Wastes. 28:558.

455b. Hickerson, R. C. and McMahon, E. K. 1960. Spray irrigation of wood distillation wastes. J. Water Pollution Control Federation, 32, 55.

467a. Hoover, S. R. and Kokes, E. L. 1947. The effect of pH upon protioloysis by papain. J. Biol. Chem. 167:199.

477a. Hopkins, G. J. and Hopkins, O. C. 1961. Whey stabilization lagoons. Symposium on Waste Treatment by Oxidation Ponds. Nagpur, India, Central Public Health Engineering Research Institute.

482a. Howland, W. E. 1957. Flow over porous media as in a trickling filter. Proc. 12th Ind. Waste Conf. Purdue Univ. May, 1957, p. 435.

500a. Ingram, W. Efficiency of various methods of treatment, milk plant wastes, New York State Water Pollution Control Board Research Report #2, 1959.

504a. Iowa State Department of Health, Division of Public Health Engineering. 1952. Polices concerning preparation and submission of plans and specifications for sewage systems and sewage treatment plants. Des Moines, Iowa.

508a. Israelson, O. W. and Hansen, V. E. 1962. Irrigation Principles and Practices, 3rd Edn. Wiley, N. Y.

575b. Kornegay, B. H. and Andrews, J. F. 1969. Application of the continuous culture theory to the trickling filter process. Paper presented at the 245th Annual Purdue Ind. Waste Conf. Purdue Univ. Lafayette, Indiana, May 6-8.

598a. Kugleman, I. J. and McCarty, P. L. 1964. Proceedings of the 19th Ind. Waste Conf. Purdue Univ.

610a. Lawton, G. W. and Eggert, C. V. 1957. Effect of high sodium chloride concentration on trickling filter slimes. Sew. Ind. Wastes. 29:1228-1236.

610b. Lawrence, A. and McCarty, P. L. 1967. Kinetics of methane fermentation in anaerobic waste treatment. Technical Report 75, Dept. of Civil Engineering, Stanford University, Feb., 1967.

637a. Luthen, J. N., Ed. 1957. Drainage of agricultural lands. Am. Soc. Agronomy No. 7, Academic Press, N. Y.

651a. Malina, J. E., Jr. and Miholitis, E. M. 1968. New developments in the anaerobic digestion of sludges. In Gloyna and Eckenfelder (402a) Adv. In Water Quality Improvements.

654a. Mancy, K. H.,and Barlage, W. E., Jr. 1968. Mechanism of interference of surface active agents with gas transfer with aeration systems in Gloyna and Eckenfelder (402a).

654b. Mancy, K. H. and Okun, D. A. 1963. Effect of surface active agents on the rate of oxygen transfer. In Advances in Biological Waste Treatment., Eckenfelder, W. W. and McCabe, J. editors, Pergamon, Oxford.

654c. Mancini, J. L. and Barnhart, E. L. Industrial waste treatment in aerated lagoons. In Eckenfelder and Cloyna. (402a).

654d. Mancini, J. and Barnhart, E. 1965. Industrial waste treatment in aerated lagoons. Special lecture series on Advances in Water Quality Improvement. Univ. of Texas, April. In Eckenfelder (314).

657a. Marais, G. v. R. 1966. New factors in the design, operation, and performance of waste stabilization ponds. Eul. World Health Org. 34.

657b. Marais, G. v. R. and Shaw, V. A. 1961. A rational theory for the design of sewage stabilization ponds in Central and South Africa. (S. African Inst. Civil Engr. 3, 11.)

657c. Mariais, G. v. R. 1964. New factors in the design-operation and performance of waste stabilization ponds with special reference to health. Expert Committee Meeting on Environmental Change and Resulting Impacts on Health, World Health Organization, p. 17 in Gloyna (402).

660a. Marki, E. 1964. Results of experiments by EWAG with the rotating biological filter. Eidg. Technische Hochschule Zurich-Fortbildungskurs EWAG.

669a. McCabe, Bro. J. and Eckenfelder, W. W., Jr. 1956. Biological treatment of sewage and indus trial wastes. Vol. I: Aerobic Oxidation, Reinhold, N. Y., 393 pp.

670a. McCarty, P. L. 1965. Thermodynamics of biological synthesis and growth. In Advances in Water Pollution Research, Vol. II, J. K. Baars, Ed. (Proc. 2nd Int. Conf., Tokyo, Aug. 1964).

670b. McCarty, P. L. 1970. Biological treatment of food processing wastes. In Proc. 1st Nat. Symp. on Food Proc. Wastes, Portland, Oregon, April 6-8.

670c. McCarty, P. L. 1968. Anaerobic treatment of soluble wastes. In Gloyna, E. F. and Eckenfelder, W. W., Jr. Editors, Adv. in Water Quality Improvement (402a).

670d. McCarty, P. L. 1966. Kinetics of waste assimulation in anaerobic treatment. Developments in Industrial Microbiology. Washington, D. C. American Institute of Biological Sciences.

670e. McCarty, P. L. 1964. Public Works. Sept.-Dec.

670e. McCarty, P. L. and Broderson. 1962. J. Water Pollution Control Fedn. 34:11.

687a. McKeown, J. J. and Okun, D. A. 1963. Effect of surface active agents on oxygen bubble characteristics. Advances in Biological Waste Treatment. Eckenfelder, W. W. and McCabe, J. Pergamon, Oxford, pp. 113.

710. Mishukov, B. G. Performance of a low pressure aeration tank for biochemical clarification of dairy waste waters. Sin. tekhn. Leningrad (USSR), 1964, 26; Chemical abstracts 62, 1288, 1965.

732a. Mueller, H. F. (See Water Pollution Abstracts, 1956, Vol. 29, Abstract No. 1918).

747a. Muskat, J. 1960. Erfahrungen mit Oxydationsgraben. Des.-Ing. 83, 2.

747a. Muskat, J. 1960. Ges. Ing. 83:2-11 in Replok, V. H. and Nehrokorn, A. 873, 751.

749a. National Research Council. 1946. Sewage Treatment at Military Installations. Sewage Works Journal 18:796.

751a. Nehrkorn, A. and Reploh, H. 1966. Experiences obtained with oxidation trenches in the purification of dairy effluent. Gesundh, Ingr. A 7:143. (In D. S. A. 29:98, 1967).

751b. Neighbor, J. B. 1970. Aerated lagoons Minnesota towns, wastes, Civil Engineering, Dec. 1970.

779a. Oxford, H. E., Heukelekian, H. and Isenberg, E. 1963. Effect of sludge loading and dissolved oxygen on the performance of the activated sludge process. Adv. in Biol. Waste Treatment. Proc. 3rd. Conf. on Biol. Waste Treatment, Manhatten Col.

779a. Oswald, W. J. 1963. In Eckenfelder, W. W., Jr. and McCabe, B. J. Eds, pp. 357-63. Adv. in Biol. Waste. Treat. Pergamon Press, N. Y.

779b. Oswald, W. J. et al. Progress Report No. 8. Studies of photosynthetic oxygenation I. Pilot plant experiments. Sanitary Research Laboratory, University of California, Issue No. 9. I.E.R. Series 54, 1958.

779b. Oxford, H. E. and Ingram, W. T. Deoxygenation of sewage. I and II Sew. Ind. Wastes 25:(4)419; III 25:(5)566.

779c. Oswald, W. J. 1963. Rational design of waste ponds. Proceedings of Symposium on Waste Treatment by Oxidation Ponds. Nagpur, India: Essential Public Health Research Institute.

779d. Oswald, W. J. Et. al. 1957. Algae in waste treatment. Sew. Ind. Wastes 29:437-455.

779e. Owsald, W. J. and Gotaas, H. B. 1957. Photosynthesis is sewage treatment. Trans. ASCE 122:73-105.

787a. Parker, C. P. 1971. Treatment of whey wastes by methane fermentation. Proceedings Second National Symposium on Food Processing Wastes, April, Denver, Colo.

796a. Pearson, E. A. 1966. Kinetics of biological treatment. Special Lecture Series: Advances in Water Quality Improvement, University of Texas, Austin, April 6, 1966.

796b. Pearson, E. A. 1968. Kinetics of biological treatment. In Gloyna and Eckenfelder, (402a) Adv. in Water Qual. Improvement.

803a. Phelps, E. B. and Beran, J. G. 1942. A laboratory study of the Guggenheim bio-chemical process. Sew. Works J. 14:104.

804a. Phelps, E. B. and Celz, C. J. 1948. Public Health Engineering. 1,2. New York, John Wiley & Sons.

815a. Pipes, W. O. 1968. An atlas of activated sludge types. Report on Grant No. WP - 00588 - 04, FWPCA USDI, Civil Engrng Dept. Northwestern University, Evanston, Ill.

820a. Placak, O. R. and Ruchhoft, C. C. 1947. Public Health Reports. 62:697.

821a. Plock, K., Bock, C. and Lembke, A. 1938. Molkeriztg Hildesh. 52:1089. Cited in Southgate (1040).

822a. Popel, F. 1964. Construction, degredation capacity and dimensioning of rotating biological filters. Eidg. Technische Hochschule, Zurich-Fortbildungskurs EWAG.

834a. Proges, N., Jasewicz, L. and Hoover, S. R. 1955. Principles of biological oxidation, Ch 1.3. In MaCabe and Eckenfelder (669a).

834b. Proges, N., Michener, T. S., Jr., Jasewicz, L. and Hoover, S. R. 1960. Treatment of dairy waste by aeration: Theory, design, construction, operation: USDA Handbook No. 176, ARS. USDA.

838a. Porges, Ralph. 1964. The principles and practices of a aerobic treatment in poultry waste disposal aerobic stabilization ponds. Paper presented at the Poultry Waste Management Symposium, Lincoln, Nebraska.

857a. Quirk, T. P., Lawler, J. F. and Matusky, F. E. 1968. Unpublished Wastewater Facilities Report, Walton, N. Y.

857b. Quirk, T. P., Walter, J. P., and Matusky, F. E. 1970. Packed tower trickling filtration of whey effluence. Draft report for USDI, FEWA Office of Research and Development Industrial Pollution Control Branch, July, 1970.

874a. Richards, L. A. Ed. 1954. Diagnosis and improvement of saline and alkali solid. USDA Agr. Handbook No. 60 in revision.

877a. Rich, L. G. 1963. Unit Processes of Sanitary Engineering. Wiley, B. Y. 190 pp.

923a. Sawyer, C. N. Unpublished data. In McCabe and Eckenfelder (670).

923b. Sawyer, C. B. 1968. New concepts in aerated lagoon design and operation in Gloyna and Eckenfelder.

923c. Sawyer, C. N. 1957. In Biological Treatment of Sewage and Industrial Wastes, Vol. I. McCabe, J. and Eckenfelder, W. W. Jr., Editors. Rinehold, New York.

964a. Schultz, K. L. 1957. Experimental vertical screen trickling filter. Sew. Ind. Wastes 29:(4)458.

964b. Schultz, K. L. 1959. Hydraulic load, organic load and efficiency in trickling filters. Paper presented at 32ne An. Mfg. FSIWA, Dallas, Texas, Oct. 1959.

965a. Schulze, K. C. 1960. Trickling filter performance. J. Water Poll. Cont. Fed., 32, 3.

967. Schulze, K. L. 1960. Load and efficiency of trickling filters. J.W.P.C.F. 32:(3)245.

967a. Schulze, K. L. 1963. Advances in biological waste treatment. Press, Oxford, England.

967b. Achulze, K. L. 1963. Internal Journal Air and Water Pollution. 5:249.

984a. Schwab, G. O., Frevert, R. K., Edminster, T. W. and Barnes, K. K. 1966. Soil and Water Conservation Engineering, 2nd Edn. Wiley, N. Y.

988a. Sharratt, W. J., Paterson, A. E. and Calbert, H. E. 1959. Whey as a source of plant nutrients and its effect on the soil. J. Dairy Sci., 42.

1015a. Sinkoff, M. D., Porges, R. and McDermott, J. H. 1959. Mean residence time of a liquid in a trickling filter. Proc. ASCE, 85(SA6).

1035a. Southgate, B. A. 1948. Dairy Indus. 13:235.

1043a. Speece, R. E. and McCarty, P. L. 1964. Nutrient requirements and biological solids accumulation and anaerobic digestion. Advances in Water Pollution Research, Eckenfelder, W. W. Jr., editor, Volume 2, New York, MacMillen Co.

1045a. Stack, V. T., Jr. 1957. Theoretical performance of the trickling filter process. Sewage Ind. Wastes, 29, 9.

1056a. Steffan, A. J. 1963. J. Water Pol. Contl. Fed. 35:4, 440.

1058a. Stewart, M. J. 1964. Activated sludge process variations: the complete spectrum. Water Sew. Works III:(4)153-158; (5) 246-249; (6)295-297.

1058b. Stewart, M. J. 1958. Reaction kinetics and operational parameters of continuous flow anaerobic fermentation process. Sanitary Engineering Research Laboratory Report No. 2. University of California, Berkley, California.

1061a. Stone, R. 1953. Land disposal of sewage and industrial wastes. Sewage and Industr. Wastes, 25, 406.

1075a. Suwannakarn, V. and Gloyna, E. F. 1964. Efect de la Temperatura en el Tratamiento de Aquas Residuales Mediante Estanques de Establizacion, Boletin de la Officina Santaria Panamericana, World Health Organization Ano 33, 61, 128-139.

1088a. Svobada, M., Gillar, J., Salplachta, J., Hlavka, G., Stelclova, D. and Marvan, P. 1964. Secondary treatment of dairy waste on a deep trickling filter. Vodni Hospodarstri 14:219-222.

1088b. Svoboda, M., Gillar, J., Salplachta, J., Hlavaka, G. and Stelcova, D. 1966. Purification of dairy waste by means of a biological tower filter. 7th Int. Dairy Cong. (Munich) E/F: 723-734.

1097a. Svore, J. H. 1968. Waste stabilization pond practices in the United States. In Gloyna, E. F. and Eckenfelder, W. W. Jr., Advances in Water Quality Improvement (402a).

1104a. Tennery, M. W. and Stumm, W. 1965. Chemical flocculation of microorganisms in biological waste treatment. J. Water Pol. Cont. Fed. 37:1370.

1121a. Timson, W. J. and Dunn, C. G. 1960. Mechanism of gas absorption from bubbles under shear. Ind Eng. Chem. 52:799.

1122a. Tomlinson, T. G. and Hall. 1950. Public Wks. and Munic. Services Congress Rep. p. 600 as cited in Southgate (1040).

1123a. Torpey, W. N. 1955. Loading to failure of a pilot high rate digester. Sewage and Industrial Waste 27:121.

1125a. Trebler, H. A. 1944. Symposium on milk wastes, Proceedings 1st Industrial Waste Utilization Conference, Purdue University.

1145a. Tribyslov, 1966. Technical and economical study of Czechoslovak dairy waste treatment plants in Annual Report Dairy Research Institute. Prague.

1152a. Underkofler, L. A. and Hickey, R. J. 1954. Industrial fermentations. Vol. I. Chemical Publishing Co. Inc. New York.

1165a. United States Public Health Service. 1943. Industrial Waste Guides, Supplement D, Appendix 8, 1162-1182.

1166a. U. S. Soil Conservation Service. Regional Engineering Handbook. Ch. VI. Conservation Irrigation, Pacific Region. XII. Portland, Oregon.

1183a. Velz, C. S. 1968. A basic law for the performance of the trickling filters. Sew. Works J., 20, 4.

1208a. Waholz, G., Lembke, A., Gronau, J., Koster, H. and Schmidt, H. 1968. Die Abwasserverhaltnisse der Molkerein. Kieler Milschwirtschaftliche Forschungebericht No. 20 no. 5.

1240a. Wheatland, A. B. 1970. Report at the Society of Dairy Technology Annual Meeting, London. October 26. As reported in Dairy Industries, Dec. 1970.

1278a. Wuhrmann, K. 1964. Hauptwirkungen und Wechselwirkungen einiger Betreibsparameter im Belebtschlamm system. Ergebnisse mehrjahringer Grossversuche. Schweiz. Z. Hydrol. 26:218-270.

1278b. Suhrmann, K. 1968. Research developments in regard to concept and base values of the activated sludge system. In Gloyna, E. F. and Eckenfelder, W. W. Jr. Adv. in Water Qual. Impt. (402a).

SECTION XIII

APPENDICES

Page

SURVEY FORMS USED IN STUDY 523

BIBLIOGRAPHY - ANNOTATION 531

DAIRY FOOD PLANT WASTE GENERAL QUESTIONNAIRE FOR INVESTIGATION OF THE STATE OF THE ART OF DAIRY FOOD PLANT WASTES FOR THE FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

by

W. J. Harper - J. L. Blaisdell

Department of Dairy Technology
The Ohio State University
Columbus, Ohio

NAME OF PLANT: ______________________________ **DATE:** __________

Street: ____________________ City: ____________________

State: ______________ Zip __________ Population ______________

Individual in Charge Waste Systems: ______________ Mgr. ______________

Milk Received: __________ gal/day __________ lbs/day ________ % Bulk Milk

________ % Can Milk. Processing-Days/Week: ______ Days/Month ______________

Non-Fat Solids Loss: __________ %/Month. Fat Loss ______________ %/Month

PRODUCTS MANUFACTURED:

A ______________, B ______________, C ______________

D ______________, E ______________, F ______________

____

____

VOLUME PRODUCED/DAY:

A ______________, B ______________, C ______________,

D ______________, E ______________, F ______________,

____

____

Preceding page blank

WATER USAGE:

SOURCES:

City: ____________ Gal/Month: From ______ Lake, ______ River, ______ Well.

Plant: ___________ Gal/Month: From ______ Lake, ______ River, ______ Well.

Temperature: City Water _______, Plant Water _______; pH: City Water _______.

Plant Water _______; Dissolved O : City Water _______, Plant Water _________;

Chloride: City Water _________, Plant Water _________.

CHEMICAL TREATMENT METHOD: City __________________, Plant ____________________

BACTERIOLOGICAL TREATMENT: City __________________, Plant ____________________

COOLING WATER: _____________ Gal/Month, SOURCE____________ UNIT COST _________

METHOD OF COOLING__________________________REFRIGERATION USED __________/Mo.

WATER REUSE: Total _____________________Gal/Month Treatment for

Reuse A ____________________ B _________________ Reused for _______________A

B___________________________ C _________________ D___________________________

WASTE STREAMS:

TO SEWER: Type _______________________Volume/Day _________________________

Type _______________________Volume/Day _________________________

Type _______________________Volume/Day _________________________

Type _______________________Volume/Day _________________________

Total ______________Volume/Day Volume Treated by City ___________

Volume Untreated ____________________

SEGREGATED FOR TREATMENT:

Type _______________________ Volume/Day _________________________

Type _______________________ Volume/Day _________________________

Type _______________________ Volume/Day _________________________

Type _______________________ Volume/Day _________________________

TOTAL VOLUME/DAY ______________________

WASTE SAMPLING:

SEWER WASTES:

Point of Sampling:____________________ Sample Taken By______________

Sampling Frequency____________________ Sample Volume

Method of Sampling ____

____

____

SEGREGATED WASTES:

Point of Sampling: A____________ B _____________ C _____________

Sample Taken By: A____________ B _____________ C _____________

Sample Frequency: A____________ B _____________ C _____________

Sample Volume: A____________ B _____________ C _____________

Sampling Method: A ____

B ____

C ____

WASTE COMPOSITION ANALYSES:

Analyses Are Made For: BOD______; COD ______; pH ______; CHLORIDE ________

Temperature ______; Phosphate _________; Soluble Solids ______________;

Volatile Soluble Solids __________; Total Solids ____________________;

Fat ____________; Nitrogen _________________; ____________________.

The Municipality Requires Analyses For _______________________________

______________________________ of the Above. These analyses Must

Be Made ____ (Mo, Wk, Day)

Analyses Made By: Municipality ______________; Plant ____________________;

Outside Laboratory ________________________.

WASTE COMPOSITION:

SEWER WASTES (MONTHLY BASIS)

BOD: Minimum ______________ Maximum ____________ Average __________/Month

COD: Minimum ______________ Maximum ____________ Average __________/Month

TEMPERATURE: Minimum __________ Maximum ____________ Average __________/Month

pH: Minimum ______________ Maximum ____________ Average __________/Month

TOTAL SOLID: Minimum __________ Maximum ____________ Average __________/Month

SOL. SOLIDS: Minimum __________ Maximum ____________ Average __________/Month

VOLATILE SOLIDS: Minimum ________ Maximum ________ Average __________ /Month

FAT: Minimum ______________ Maximum ____________ Average __________ /Month

CHLORIDE: Minimum __________ Maximum ____________ Average __________/Month

PHOSPHATE: Minimum _________ Maximum ____________ Average __________/Month

NITROGEN: Minimum _________ Maximum ____________ Average __________/Month

________: Minimum _________ Maximum ____________ Average __________/Month

________: Minimum _________ Maximum ____________ Average __________/Month

SEGREGATED WASTES: (MONTHLY BASIS)

BOD: Minimum ____

Maximum ____

Average ____

COD: Minimum ____

Maximum ____

Average ____

TEMPERATURE: Minimum ____

Maximum ____

Average ____

pH: **Minimum** ____________________

Maximum ____________________

Average ____________________

OTHER ANALYSES: ____________________

____

____

____

____

____

COMPOSITION AFTER PRIMARY TREATMENT BY PLANT:

BOD: **Minimum** ____________________

Maximum ____________________

Average ____________________

COD: **Minimum** ____________________

Maximum ____________________

Average ____________________

OTHER ANALYSES: ____________________

____

____

____

____

____

____

COMPOSITION AFTER SECONDARY TREATMENT BY PLANT:

BOD: Minimum ______________________________

Maximum ______________________________

Average ______________________________

COD: Minimum ______________________________

Maximum ______________________________

Average ______________________________

OTHER ANALYSES: ______________________________

____

____

____

____

____

CLEANING AND SANITIZING PROCEDURES:

% CIP: ____________ % Automated ____________

CLEANING COMPOUNDS USED:

A ______________________________, Lbs/Month ____________

B ______________________________, Lbs/Month ____________

C ______________________________, Lbs/Month ____________

D ______________________________, Lbs/Month ____________

SANITIZERS USED:

A ______________________________, Lbs/Month ____________

B ______________________________, Lbs/Month ____________

WATER VOLUME USED FOR CLEANING (PER CYCLE FOR EACH CIRCUIT AND TOTAL PER MONTH)

____

____

____

WATER VOLUME USED FOR SANITIZING (PER CYCLE FOR EACH CIRCUIT AND TOTAL PER MONTH)

____

____

____

WASTE TREATMENT COSTS:

SEWER WASTES: ______________ $ ________(unit); Cost/Month ____________

Charges Made on Basis of: BOD ________, Water Usage ________ Cost ________

Segregated Wastes: COST/MONTH ______________________________

What is the formula used by the municipality for computation of sewer charges:

____

What are the costs per month for biological and chemical waste treatment by your plant? ______________________________

What are the haulage and other costs (or credits) of untreated segregated wastes? ______________________________

WASTE TREATMENT SYSTEMS:

SEWER WASTES: Indicate the sequence of physical or biological treatments.

____

____

____

____

____

BOD TREATED ______________ BOD TO WATERSHED ______________

PLANT WASTE TREATMENT

NON-SEGREGATED WASTE TREATMENT (Indicate the sequence of primary and secondary waste treatments) ______________________

____

____

SEGREGATED WASTES TREATED BY: (Sequence of primary and secondary) __________

____

____

RESIDENCE TIME OF WASTES:

SEWER WASTES: Primary __________ Secondary __________ Tertiary __________

UNSEGREGATED PLANT WASTES: Primary __________ Secondary __________

Tertiary __________

SEGREGATED PLANT WASTES: Primary __________ Secondary __________

Tertiary __________

WASTE TREATMENT PROBLEMS:

(SEGREGATION, SAMPLING, TESTING, FOAMING, BULKING, ODOR, RESIDENCE TIME, PERIODIC "PUKING", START-UP PROBLEMS, TEMPERATURE PROBLEMS SUCH AS POOR PERFORMANCE OR FREEZING, pH PROBLEMS, BOD VARIABILITY, RUN OFF PROBLEMS, CHANGE IN SOIL PERMEABILITY FOR IRRIGATION SYSTEMS.)

____

____

____

____

____

____

____

____

RETURN PRODUCTS: Volume/day (a) __________ (b) __________

(c) __________ (d) __________ (e) __________

METHOD OF HANDLING RETURNS: __________________________________

____

____

BIBLIOGRAPHY - ANNOTATION

To assist those interested in various aspects of dairy wastes and waste treatment, the references in the bibliography have been organized by various subject matter areas. In each subject matter area, the references have been separated into the following categories:

Descriptive information
Industrial experiences
Original research
Regulations
Reviews and surveys
Books
Miscellaneous

I. DAIRY PRODUCTS

A. Milk:

Descriptive information

8
43
44
54
66
68
73
75
78
85
90
101a
103
104
105
106
112
116
118
121
122
127
143
144
166
176
179
192
202
203
207
208
212
214
216
248
252
253
264
273
274
275
276
277
286
296
298
300
305
314
327
334
337
338
340
342
370
379
380
393
401
411
412
420
423
447
463
467
480
481
483
491
496
509
524
533
537
548
553
560
561
581
585
586
587
588
590
591
596
612
621
627
638
645
646
647
648
650
657
660
665
682
683
684
699
703
704
715
717
719
722
738
739
740
753
757
762
763
765
767
790
798
800
803
810
814
819
822
827
829
844
847
851
853
854
856
869
875
885
886
887
888
889
890
894
898
907
909
915
917

922
925
926
928
937
941
944
945
946
948
960
962
968
973
974
975
976
980
981
982
983
985
986
1012
1015
1017
1018
1019
1029
1034
1037
1038
1039
1049
1050
1054
1055
1057
1059
1066
1069
1080
1087
1091
1099
1105
1106
1108
1110
1111
1118
1124
1125
1126
1130
1131
1132
1133
1137
1138
1147
1164
1165
1188
1191
1195
1196
1198
1205
1207
1212
1214
1227
1228
1229
1240
1242
1245
1251
1255
1256
1258
1259
1272
1273
1275
1293

Industrial experiences

16
23
25
26
28
29
30
32
33
36
41
51
54
55
56
59
60
64
65
67
74
76
79
80
82
94
95
97
98
100
101
108
115
132
133
146
147
153
154
159
160
170
176
179
180
185
186
187
191
210
211
215
217
218
219
227
228
239
241
250
254
260
268
269
272
285
299
301
305
307
308
309
325
326
327
329
330
331
332
333
336
339
347
354
364
365
367
371
372
406
413
437
439
443
445
448
449
480
481
484
490
492
496
500
503
511
513
521
522
527
530
531
535
542
558
564
566
567
598
606
607
617
628
629
635
638
649
652
653
659
661
665
674
676
678
680
692
697
713
714
718
720
721
736
741
744
745
747
748
752
756
758
765
768
769
770

774
776
777
780
794
801
813
823
828
829
838
839
840
846
852
855
857
868
872
873
876
900
905
906
907
909
913
916
923
927
930
932
934
936
949
950
952
967
969
970
975
982
1012
1014
1018
1021
1022
1023
1036
1039
1047
1062
1064
1073
1084
1085
1093
1095
1096
1108
1111
1129
1133
1135
1139
1145
1150
1151
1152
1180
1182
1183
1188
1189
1190
1191
1192
1193
1199
1202
1203
1205
1206
1209
1210
1211
1212
1213
1236
1238
1246
1247
1250
1253
1257
1258
1260
1261
1262
1263
1273
1276
1277
1286
1287
1291

Original research

2
3
7
21
24
27
30
52
55
59
65
72
82
83
84
94
99
121
122
149
159
160
171
183
188
189
190
198
201
204
205
206
227
230
231
232
233
234
263
283
284
289
295
305
318
323
330
343
366
377
382
391
392
397
398
399
407
414
416
424
449
460
471
472
473
475
514
520
528
538
539
549
554
565
576
577
578
584
592
593
594
595
597
599
604
613
620
625
634
659
674
690
693
694
710
711
731
746
764
775
778
785
787
795
800
802
805
806
807
808
809
811
812
815
823
825
826
832
834
836
841
842
855
864
867
868
869
870
872
883
891
893
895
903
904
931
938
939
940
958
963
972
1019
1022
1024
1030
1031
1032
1033
1043
1058
1066
1071
1072
1073
1082

1083
1085
1086
1087
1089
1090
1092
1097
1103
1107
1109
1113
1114
1117
1123
1127
1140
1142
1144
1146
1178
1199
1206
1209
1210
1229
1232
1233
1246
1273
1276
1283
1284
1290
1291

Regulations

39
53
89
154
177
178
261
292
309
608
662
735
772
799
880
881
883
1020
1207
1216

Reviews and surveys

61
174
261
262
263
355
363
466
523
616
647
734
750
760
828
833
897
898
901
936
943
951
971
976
1020
1025
1040
1043
1048
1062
1074
1112
1134
1136
1141
1155
1156
1157
1158
1159
1160
1161
1162
1163
1166
1167
1168
1169
1170
1171
1172
1173
1174
1175
1176
1204
1213
1254
1274
1285

Miscellaneous

96
124
222
224
225
237
238
243
255
258
259
265
266
270
271
295
311
315
321
322
335
353
374
378
431
435
458
470
489
504
512
518
551
583
602
619
630
640
702
728
729
737
754
771
773
781
797
804
830
849
871
874
882
892
899
910
914
919
979
1013
1035
1065
1067
1115
1120
1121
1128
1200
1222
1241
1244
1282

B. Cheese:

Descriptive information

757
917

Industrial experiences

14
25
28
159
328
331
347
375
439
534
566
653
661
698
726
744
752
821
957
969
988
1002
1181
1197
1208
1252

Original research

102
159
328
385
554
791
799
821
955
961
988
1002
1142
1252

Regulations

662

Miscellaneous

341

C. Whey:

Descriptive information

55
86
213
305
358
433
482
553
571
644
663
675
814
929
1006
1045
1055
1068
1072
1078
1081
1177
1221
1281

Industrial experiences

15
37
100
123
124
136
137
138
139
152
278
305
478
557
584
610
623
698
769
800
855
953
991
1053
1071
1077
1281

Original research

2
18
58
87
88
91
92
99
129
193
201
249
279
283
284
289
305
345
381
418
425
422
477
478
502
515
516
517
550
610
611
614
654
663
701
712
732

761
779
800
831
834
855
858
908
911
955
958
999
1076
1079
1086
1098
1116
1154
1177
1184
1185
1217
1218
1219
1220
1265
1266
1280

Reviews and surveys

18
766
918
1006

Miscellaneous

124
643

D. Cottage Cheese:

Descriptive information

354

Original research

425
862

E. Evaporated and Condensed Milk:

Descriptive information

1240

Industrial experiences

135
140
301
330
388
439
959

Original research

330
1043

Reviews and surveys

1043

F. Ice Cream and Frozen Desserts:

Industrial experiences

77
331
687
942

Regulations

39

G. __Buttermilk and Cultured Products__:

Descriptive information

127 305 1006

Industrial experiences

305 371 800 969

Original research

2 284 305 800

Reviews and surveys

1006

H. __Dry Milk__:

Descriptive information

208

Industrial experiences

62 488 653

I. __Simulated Dairy Wastes__:

Original research

21 381 426 837 1043

Reviews and surveys

1043

J. __Skim Milk__:

Industrial experiences

278 800

Original research

381 426 800 837
402 624 835

Miscellaneous

871

K. __Butter__:

Descriptive information

117 757 917

Industrial experiences

159 371 417 439 744 1149 1181 1208

Original research

159 368 385 529 554 668 1143

II. DAIRY TRADE WASTE WATERS, COMPOSITION

A. Proteins:

Descriptive information

38 621 809 889 911 918

Industrial experience

385 546 547 649 920

Original research

21 205 469 476 532 544 547 565 659 808 826 835 1033 1070 1144 1268

Reviews and Surveys

545

B. Lipids:

Descriptive information

41 621 918

Industrial experience

41 546 821 844 988

Original research

510 528 631 632 633

Reviews and surveys

545

C. Carbohydrates:

Descriptive information

214 225 621 806 809 814 918 1006 1272

Industrial experience

302
347
526
546
920
942
988
1217

Original research

3
22
91
129
164
193
204
205
226
233
345
458
462
469
476
485
508
520
554
563
620
659
665
694
783
808
820
826
830
835
836
896
908
924
953
997
1033
1070
1082
1083
1144
1179
1284

Reviews and surveys

545

D. Analytical methods:

Descriptive information

171
189
217
275
288
430
524
547
736
830
1019
1115

Industrial experience

936

Original research

12
13
197
229
243
303
374
386
391
399
456
458
462
510
526
527
532
552
630
631
632
633
668
743
746
797
874
883
896
924
936
997
1033
1058
1103
1143
1144
1153
1194
1267

Reviews and surveys

386
545

E. BOD test:

Descriptive information

10
51
162
168
174
176
193
253
293
294
326
338
596
690
740
741
745
759
760
810
814
926
928
940
968
971
976
980
981
983
986
1018
1019
1037
1056
1134
1138
1186
1206
1207
1272
1273

Industrial experience

14
15
16
19
25
41
46
50
56
62
65
77
102
105
128
133
135
136
139
146
159
160
174
179
180
188
194
200
201
219
228
260
272
275
308
330
331
332
333
336
361
371
375
382
385
407
413
416
417
427
438
439
500
527
534
542
549
554
557
584
586
649
652
653
661
678
687
698
721
728
729
739
744
752
756
768
769
775
776
777
794
800
811
821
844
894
905
913
920
931
934
936
937
941
942
946
947
949
963
988
1002
1014
1023
1034
1036
1050
1053
1054
1055
1066
1087
1089
1093
1095
1116
1133
1135
1142
1181
1182
1191
1197
1202
1208
1209
1210
1212
1213
1228
1247
1260
1261
1262
1263
1272
1273
1286
1287

Original research

13
188
197
198
208
249
303
323
328
339
373
374
387
390
391
392
397
398
402
426
451
452
453
455
471
472
477
478
518
519
538
539
552
565
572
584
604
611
624
630
641
659
677
678
705
711
724
746
783
895
802
815
825
836
837
867
869
872
874
924
925
931
946
962
1001
1027
1043
1051
1058
1070
1086
1094
1095
1101
1116
1153
1179
1184
1194
1234
1267
1272

Regulations

53

Reviews and surveys

7
55
262
363
475
523
616
750
823
1164

F. COD test:

Descriptive information

162
176
253
338
968
971
976
980
981
983
1018
1019
1206

Industrial experience

65
122
159
160
180
228
240
275
375
382
385
439
554
800
920
937
941
949
988
1002
1034
1055
1182
1202
1209
1210
1212
1261
1287

Original research

197
208
233
234
243
373
374
387
424
426
455
472
477
518
538
539
552
565
630
659
724
795
797
802
831
834
836
867
869
874
925
1058
1067
1070
1179
1267
1268
1284

Reviews and surveys

363
750
823
1164

G. Suspended Solids:

Descriptive information

176
741
968
976
981
983
1019
1206

Industrial experience

19
136
140
159
262
278
330
331
336
375
385
413
439
649
739
776
1002
1014
1034
1182
1261
1273
1285

Original research

711
874

Reviews and surveys

363

H. Volume:

Descriptive information

41
174
273
338
339
533
596
762
851
917
926
928
940
968
971
976
980
981
983
986
1018
1019
1056
1206
1207
1272

Industrial experiences

15
16
19
46
50
54
62
65
102
105
108
123
128
133
139
159
160
170
176
179
180
218
228
241
260
272
275
308
330
331
332
336
367
371
375
385
407
417
423
439
449
500
527
534
549
584
635
649
653
659
678
721
729
739
744
768
769
770
794
800
821
844
910
920
931
937
941
942
949
969
988
1002
1034
1036
1050
1055
1066
1084
1087
1089
1181
1182
1183
1191
1197
1201
1202
1208
1209
1211
1212
1228
1260
1261
1262
1273
1286
1287

Original research

59
208
305
426
584
677
678
869
931
1234
1276

Reviews and surveys

261
262
363
750
823
1164

I. Nitrogen:

Descriptive information

759

Industrial experience

122
231
1262
1285

Original research

231
711
869

Reviews and surveys

1187

J. pH:

Descriptive information

621
971

Industrial experience

23
139
231
278
382
385
416
439
649
721
739
756
844
920
988
1093
1096
1116
1209
1210
1212
1262

Original research

21
22
231
396
397
398
424
508
526
565
659
785
815
872
1043
1066
1070
1098
1116

K. Chloride:

Original research

552

L. Temperature

Descriptive information

621

Industrial experience

139
371
382
649
1093
1116

Original research

402
526
659
1070
1098
1116

M. Phosphate:

Descriptive information

465

Industrial experiences

122

Original research

22
869

III. DAIRY TRADE WASTE TREATMENT METHODS

A. Water Reuse, Conservation:

Descriptive information

8
17
34
51
55
71
100
164
174
176
212
218
253
257
274
275
284
326
338
340
346
364
372
379
394
411
429
459
483
486
533
551
553
596
679
683
714
728
735
739
740
741
762
798
853
887
894
907
911
915
920
926
929
940
971
985
986
1011
1015
1049
1054
1088
1099
1124
1125
1126
1132
1133
1134
1137
1138
1141
1150
1205
1227
1237
1273

Industrial experience

25
36
41
103
420
445
449
487
729
752
935
949
1089
1213
1286

Original research

659
935
1052

Reviews and surveys

116
203
261
262
264
523
616
734
1164

B. Kinetics:

Original research

310
391
442
462
476
472
473
475
508
526
572
700
730
783
820
826
1153
1269

C. Activated Sludge:

Descriptive information

10
34
55
149
164
168
214
257
274
329
342
376
429
430
437
448
450
590

591
592
593
596
597
646
683
734
735
738
740
741
745
753
830
851
888
891
894
917
926
929
973
974
985
1006
1020
1037
1048
1049
1070
1109
1124
1125
1133
1137
1138
1141
1240
1272
1273
1278

Industrial experience

7
14
16
24
29
33
37
98
102
108
115
123
135
136
149
170
172
174
194
200
201
262
284
331
336
375
388
415
438
440
446
479
480
500
535
547
549
558
584
586
606
649
652
653
678
687
721
722
728
744
752
776
791
794
821
828
844
845
861
934
942
959
961
1055
1064
1087
1090
1108
1110
1111
1116
1139
1141
1145
1149
1192
1209
1210
1215
1228
1240
1272
1285

Original research

3
4
5
6
11
77
91
142
156
172
181
208
209
233
234
283
284
287
291
306
320
328
373
377
387
392
396
397
400
424
455
460
468
469
470
472
473
476
508
515
516
520
526
544
555
563
565
573
574
584
594
595
633
641
659
678
711
727
783
791
802
820
826
831
832
834
858
863
868
870
895
940
962
1001
1007
1085
1086
1102
1114
1116
1117
1123
1215
1230
1234

Reviews and surveys

38
253
275
363
447
825
827
833
1040
1187

Books

335

D. Irrigation - Ridge and Furrow:

Descriptive information

41
55
164
231
257
326
349
430
683
917
922
985
1006
1048
1258
1273

Industrial experience

15
50
365
599
949
950
951
968
969
1055

Original research

576
577
578
677
706

Reviews and surveys

363
707
1040

E. Anaerobic:

Descriptive information

430
533
894
903
985
1006
1012
1020
1037
1049
1272
1273

Industrial experience

139
140
336
535
661
696
770
942
954
1023
1024
1055
1066
1090
1180
1261
1273
1287

Original research

198
267
289
290
322
526
565
634
690
731
867
954
1043
1269
1283

Reviews and surveys

363
447
1040
1043
1122

F. Septic Tanks:

Descriptive information

55
257
274
326
534
926
985
1124
1125
1133
1137
1141
1242
1273

Industrial experience

7 25 448 687 728 1050
16 174 653 703 782

Original research'

21 231 538 690
22 524 620 841

G. Oxidation Ditches:

Descriptive information

10 100 748 798 939

Industrial experience

16 405 750 873 934 1084
132 692 791 931 936 1192

Original research

3 381 791 868 931
100 396 795 870 1276

H. Membrane Processes:

Descriptive information

740 741

Industrial experience

1280

Original research

83 478 623 673 1280

Reviews and surveys

774

I. Fish Ponds and Lagoons--aerobic, anaerobic, mixed:

Descriptive information

210 839 985 1062 1193
430 917 1006 1133 1242
683 974 1049 1137 1273

Industrial experience

23
77
90
97
104
210
219
323
413
439
443
503
542
654
768
770
777
822
855
968
1036
1055
1087
1096
1189
1231
1250

Original research

343
396
522
555
634
641
785
815
855
864
978
982

Reviews and surveys

363
838
1040

J. Trickling Filter:

Descriptive information

2
10
34
44
55
100
149
164
214
231
257
274
326
327
329
342
401
429
430
437
448
646
683
722
734
735
738
740
741
745
753
775
798
851
888
894
909
926
929
939
974
985
1006
1012
1020
1022
1037
1048
1049
1059
1124
1125
1133
1134
1135
1137
1138
1141
1150
1240
1242
1257
1258
1272
1273

Industrial experience

7
16
19
23
25
28
31
33
37
50
56
77
94
101
103
120
122
128
146
170
174
200
201
262
272
273
278
284
305
308
330
331
332
333
371
413
439
488
496
503
559
564
629
635
649
696
718
728
729
739
768
769
770
787
821
822
876
905
913
968
1014
1023
1036
1053
1087
1095
1139
1141
1180
1211
1213
1247
1250
1255
1261
1262
1263
1287

Original research

30
59
91
120
142
198
208
211
227
281
284
289
301
352
396
402
414
426
499
501
502
513
524
544
611
624
625
641
925
940
965
966
967
1009
1016
1046
1093
1095
1097
1178
1230
1283

Reviews and surveys

38
253
275
363
447
454
1040
1187

K. Spray Irrigation:

Descriptive information

7
10
36
41
55
60
143
147
164
166
207
231
251
268
309
326
430
448
530
553
612
619
675
682
683
703
717
726
735
738
739
762
765
798
851
916
917
926
929
948
956
971
974
976
985
996
1006
1012
1048
1049
1071
1105
1106
1137
1138
1150
1242
1273
1275
1293

Industrial experience

15
16
23
26
50
64
102
123
132
191
215
250
282
302
305
365
367
407
423
449
484
489
490
525
598
599
607
610
662
676
680
681
728
757
768
780
847
910
917
930
936
941
949
951
968
969
970
991
1029
1055
1139
1201
1231
1250
1281

Original research

22
495
524
576
577
578
613
677
694
706
712
842
958
999
1107
1232
1291

L. **Coagulation**:

Descriptive information

34
55
164
225
257
274
342
430
436
533
663
734
735
740
741
753
809
811
814
851
856
867
917
926
973
974
985
1006
1037
1048
1049
1056
1124
1125
1133
1137
1141
1272
1273

Industrial experience

77
174
240
305
333
347
364
368
375
385
448
557
652
756
807
852
968
1024
1036
1116
1141
1197

Original research

88
324
328
373
377
378
538
539
659
665
668
716
761
808
868
902
1066
1067
1071
1073
1085
1116
1142
1144
1177
1271
1284

Reviews and surveys

38
253
363
1040

M. **Efficiency**:

Descriptive information

262
1139
1278

Industrial experience

19
55
98
105
108
128
194
228
240
272
278
308
330
331
332
333
336
364
371
375
382
413
438
439
440
538
542
547
549
584
586
635
652
690
721
729
750
752
756
768
769
775
794
823
844
905
913
917
959
961
1014
1036
1050
1054
1055
1084
1090
1093
1095
1096
1108
1135
1188
1210
1211
1213
1228
1247
1250
1262
1263
1272
1273
1285

Original research

324
328
339
373
381
426
477
478
539
555
565
584
624
633
641
659
785
795
802
820
831
834
836
867
874
962
967
994
1001
1009
1043
1086
1094
1095
1114
1123
1184
1230
1234
1272
1284

Reviews and surveys

363

N. **Biochemistry**:

Original research

3
5
22
164
165
183
199
226
289
290
455
469
473
485
520
554
594
595
620
686
727
820
834
837
953
1007
1072
1102
1153

Reviews and surveys

55
475
828
1187

O. **Economics**:

Descriptive information

17
100
207
231
282
326
429
546
571
591
596
619
675
678
739
740
741
767
939
971
976
981
984
1006
1088
1106
1139
1141

Industrial experience

23
26
30
49
103
105
123
133
174
215
367
407
415
449
489
560
586
643
698
728
756
848
894
936
954
968
969
979
1023
1050
1055
1066
1084
1087
1093
1095
1209
1210
1247
1272
1285

Original research

30 677 925 954 1095 1144 1272

P. Microbiology and Biology:

Descriptive information

44 149 214 222 259 271 288 410 423 450 536 540 621 689 891 903 917 948 972 1020 1118 1121 1249 1274 1275

Industrial experience

24 122 200 525 777 913 949 1093 1200 1217 1255

Original research

3 4 6 11 58 83 128 164 165 183 190 193 194 199 204 205 211 226 249 255 279 281 291 318 341 343 345 373 387 391 396 397 398 399 400 424 435 442 470 471 473 485 495 513 514 554 563 572 576 577 578 611 620 665 693 694 716 725 743 785 808 820 830 835 836 858 864 895 908 953 978 993 994 1016 1043 1070 1072 1076 1082 1083 1086 1098 1184 1216 1220 1230 1265 1266 1279

Reviews and surveys

363 833 1122

Books

685 849

Q. Detergents:

Descriptive information

45 343 992 1056 1244

Industrial experience

416 656 920

Original research

1 167 287 320 324 460 639 1033 1153

Reviews and surveys

261

R. Sanitizers:

Descriptive information

162 977 992

Industrial experiences

959

Original research

167 224 238 255 494 716 1065 1066

S. Gas Transfer Methods of Aeration:

Descriptive information

289 418 536

Industrial experience

228 339 762 946

Original research

339 612 762 947

IV. DAIRY TRADE WASTE TREATMENT PROBLEMS

A. Loading:

Descriptive information

745 939

Industrial experience

25 388 913 941 1135 1273

Original research

402 641 940 1094
573 868 967

B. Bulking:

Descriptive information

342 450

Industrial experience

959

Original research

3 6 515 820 870 895

C. Foaming

Descriptive information

1056

Industrial experience

547 584 776

Original research

287 320 547 584 639 835

D. Sedimentation:

Descriptive information

7 851 911 974 1137
448 856 917 1037 1140

Industrial experience

16
19
77
307
308
375
439
757
775
969
1014
1036
1209
1287

Original research

6
287
295
321
377
529
925
1153

Reviews and surveys

38

V. DAIRY TRADE WASTE WATERS

A. Standards:

Descriptive information

8
36
55
100
141
154
162
292
309
379
412
422
431
581
637
735
755
760
981
983
1057
1237
1251

Industrial experience

36
46
662
988

Original research

1234

Regulations

2
10
36
39
41
46
53
70
89
177
178
302
369
422
608
675
738
739
772
799
880
881
883
894
1020
1207
1216
1221

Reviews and surveys

38
261
464

B. Books

315
335
336
421
505
506
512
589
615
754
804
849
892
899
912
923
1003
1013
1035
1061
1075
1238

VI. FLOW SHEETS, DAIRY PLANTS

Descriptive information

534
856
963
976

Industrial experience

79 244 273 278
489 496 567 652
770 794 828 866
959 1093 1140 1145
1149 1164 1188 1209
1228 1250 1260 1263

Original research

167
206
868

VII. FOOD PROCESSING WASTE WATERS

Descriptive information

8 357 622 638 715
767 792 822 875 887
889 904 916 952 1008
1038 1041 1056 1151 1188
1193 1256 1270 1277 1293

Industrial experience

17 31 33 43 46
54 78 114 146 192
219 282 492 566 606
607 662 775 777 866
887 903 947 949 951
1034 1042 1152 1231

Original research

17 555
665 731
1145 1249
1279

Reviews and surveys

254
409
1164

VIII. SUGARS AND SUGAR REFINERIES WASTE WATERS

Descriptive information

44 622
638 726
803 904
1038 1151

Industrial experience

26
31
37
220
223
256
333
403
419
536
537
603
762
786
903
949
1004
1005
1034

Original research

2
63
111
163
665
993
994
1005
1154
1279

IX. BREWERY WASTE WATERS

Descriptive information

638
889
1008
1277

Industrial experience

33
46
256
664
813
947
949
1034
1253

Original research

83
494
716
746
1028
1267

Reviews and surveys

1125

X. MUNICIPAL WASTE WATERS

Descriptive information

293
299
329
683
738
739
740
748
926
984
985
1006
1021
1037
1049
1071
1129
1133
1134
1137
1138
1242
1250
1272
1273
1277

Industrial experience

7
23
31
50
77
98
101
132
137
138
146
173
240
273
308
413
696
698
718
775
823
848
866
876
913
1023
1152
1180
1202
1253
1287

XI. GENERAL ARTICLES, SURVEYS, ANNUAL REPORTS, REVIEWS, AND MISCELLANEOUS ARTICLES

Descriptive information

8
20
27
32
35
66
68
69
73
75
78
85
86
90
93
95
99
107
109
110
121
124
148
150
153
185
186
192
202
212
213
216
237
239
247
258
260
263
269
270
275
277
285
286
294
296
297
300
325
334
337
340
354
356
359
362
370
389
393
404
420
432
434
444
445
463
474
480
509
511
531
548
559
560
567
579
580
583
585
587
588
601
602
604
627
628
636
638
645
646
648
650
657
660
667
671
672
674
684
697
699
701
704
714
715
719
720
735
737
742
747
755
756
758
763
764
771
773
779
789
790
801
803
805
807
812
840
854
856
857
882
884
885
886
890
893
900
914
919
921
928
938
944
945
960
964
975
989
1010
1039
1047
1054
1059
1069
1071
1080
1091
1104
1106
1120
1127
1128
1130
1131
1132
1143
1145
1147
1165
1190
1191
1195
1196
1198
1199
1203
1205
1206
1214
1227
1229
1237
1241
1243
1246
1248
1251
1256
1259
1264
1270
1277
1282
1286

Industrial experience

67
74
76
79
80
152
187
846
927
932
937
957
1017
1191
1253

Original research

72
84
87
88
187
242
251
686
710
732
819
862
864
869
1027
1079
1081
1212
1252
1271
1290

Reviews and surveys

51
61
82
96
101a
103
106
112
118
144
157
254
262
266
276
314
355
363
380
409
428
454
466
491
523
533
535
545
616
640
677
702
713
750
760
766
778
829
897
898
901
918
943
1025
1030
1031
1032
1040
1074
1112
1136
1141
1155
1156
1157
1158
1159
1160
1161
1162
1163
1166
1167
1168
1169
1170
1171
1172
1173
1174
1175
1176
1204
1236
1254